AN ANALYSIS OF ASTRONAUT PERFORMANCE CAPABILITY IN THE LUNAR ENVIRONMENT

VOLUME II

Performance Capability Support Data

MATRIX

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I.

INTRODUCTION AND SCOPE

As lunar missions of the future are being planned, a great amount of attention is being devoted toward defining the scientific objectives of the missions and experimental procedures to be followed during each mission. Experiments are being designed in the areas of geodesy, cartography, geology, geophysics, geochemistry, astronomy, bioscience, atmosphere measurement, and particles and fields. These experiments have, as their prime objective, the scientific investigation of the lunar surface, subsurface, topography, magnetic fields, radiation and thermal environment, and atmosphere. The majority of the experiments currently being designed place heavy emphasis on a human operator, monitor, and decision maker to select samples, identify unforeseen events, deploy apparatus, and observe instruments and environmental conditions.

Since the role of the man is critical in the exploration and investigation of the moon, it is essential that the capabilities and limitations of an astronaut in the lunar environment be carefully specified. Only a complete understanding of the range of performance capabilities and safety of the astronaut will assure optimal allocation of system functions to man or machine, effective design of equipment which interfaces with the man, and optimal utilization of his time.

Needs for a thorough understanding of astronaut performance and safety requirements on a lunar mission lead to a general requirement for a research program to define capabilities and limitations of astronauts to perform specific missions. This research program should parallel the programs being developed for the scientific areas of lunar geology, geochemistry, etc. The astronaut performance research program should specify individual studies to be performed to identify astronaut capabilities and potential problem areas and safety hazards, and the time sequencing of these studies. The research program is directed toward the dual objectives of defining astronaut performance capabilities in the lunar environment and supporting the man/machine interface design, operational procedures, decision rules, and training requirements associated with these items.

To date all that is known concerning astronaut performance/safety considerations on the moon has been developed from earth based simulations of the lunar environment or from analytical evaluations of expected capabilities based on available data concerning specific environmental factors. Simulation studies include investigations of astronaut performance in the gravitational, topological, and lighting environment of the moon. The degree of fidelity of these simulations has been a problem primarily due to the constraints imposed by the simulation techniques and due to insufficient understanding of the combined effects of interacting environmental factors. The data concerning the lunar environment, obtained from Ranger, Surveyor, and Lunar Orbiter missions, Soviet Luna missions, telescope observations, photometric studies, and visual reports of Apollo VIII astronauts, describe an environment which in many respects is almost completely novel and which can be expected to adversely affect astronaut performance and safety. The present study was concerned with surveying and analyzing research findings reporting potential problem areas for astronaut performance and citing the type, degree, and effect of expected performance decrements.

The report of this study is presented in two volumes. Volume I contains a summary description of the operational environment, including the lunar environment and the space suit environment, a summary description of mission operations, and a detailed description of problem areas identified for performance of mission operations in the operational environment. This volume also contains an assessment of requirements for additional research, including descriptions of individual studies and definition of the astronaut performance research program. A description of candidate experiments for astronaut performance on the lunar surface, during Early Apollo missions, is presented. Finally, a listing is presented of important conclusions drawn from the study and recommendations associated with each conclusion.

Volume II of the study report is concerned with the detailed data from which evaluations, conclusions, and recommendations included in Volume I were derived. These support data are in three general areas: lunar environment; mission, equipment, and operations; and research findings concerning astronaut performance and safety. The research findings begin with a discussion of simulation techniques and proceed through a survey and analysis of empirical data concerning visual performance, motor performance, spatial orientation, physiological factors, radiation safety, and habitability.

CHAPTER II.

DESCRIPTION OF THE LUNAR ENVIRONMENT

In the past forty years, man has learned more about the moon than in all of previous recorded history. In the last ten years, the amount of information has more than doubled again as a result of unmanned lunar fly-bys, hard landing probes, and - most recent - by the U. S. and Russian soft landings of surveyor and luna vehicles. While information is being gathered at a more rapid rate than ever before, many questions remain unanswered, and legitimate differences of opinion about the details of the lunar environment still exist. Many of these disagreements can be traced to differences in measuring instruments and in the investigative techniques employed. Others arise from the differing inferences which can be drawn from the still incomplete data about the nature of the lunar environment.

In terms of what is known of the moon, the more important facts are summarized below. The earth-moon distance varies from 221,460 to 252,700 miles with an average separation of 238,840 miles. The sidereal period of the moon is the interval between two successive conjunctions of the moon with a star as seen from the sun. This interval, representing the true period of revolution of the moon around the sun, and the duration of one complete revolution about the earth, relative to the stars, is 27 days, 7 hours, 43 minutes, and 11.5 seconds. A description of the moon as compared to the earth is presented in Table 1.

TABLE 1.

COMPARATIVE DATA FOR THE EARTH AND THE MOON

	Earth	Moon
Orbital eccentricity	.017	.0549
Orbital inclination to ecliptic	0° 0'	5° 09'
Mass	1	.0123 earth
Volume	1	.0203 earth
Escape velocity	7 mi/sec.	1.5 mi/sec.
Diameter	8,000 mi.	2160 miles

The purpose of this section is to describe those aspects of the lunar environment which conceivably could affect the performance capability, physiological integrity, or safety of an astronaut. Lunar environmental factors selected for discussion include size, atmosphere, temperature, topography, light, and radiation.

1. Size of the Moon

The diameter of the moon is approximately 2160 miles, or 3476 km. This is 27% of the diameter of the earth, which is about 8,000 miles. The circumference of the earth is more than 25,000 miles, compared to the moon's circumference of only 6,750 miles. The surface area of the moon is 14,000,000 square miles while that of the earth is 197,000,000 square miles. The actual curvature of both bodies is equal, but the apparent curvature is much greater on the moon than on earth. This becomes more apparent when radian estimates are compared. For the earth, 1 radian intercepts 4,000 miles; on the moon, a radian only intercepts 1,080 miles, or approximately one-quarter the linear distance.

2. Atmosphere

Because of the low surface gravity, 16% of the gravitational field found on earth, the lunar atmosphere is extremely rarified. For all intents and purposes, the moon has no atmosphere, the most commonly quoted estimates being between 10^{-10} and 10^{-13} that of the earth's atmosphere (Branley, 1966 and Gurshteyn, 1967). Estimates as low as 10^{-15} have been made by radio star occulation techniques. The density of the lunar atmosphere is about equal to the density of the atmosphere of the earth 200 to 300 miles above the surface. The atmospheric density above the earth's surface is presented in Figure 1. Since the moon is practically devoid of a protective gas covering the surface is continually and heavily bombarded by micrometeorites, ultraviolent radiation, and solar corpusculor and primary cosmic rays. The absence of any appreciable atmosphere is due to the low gravitational acceleration of the

FIGURE 1.

ATMOSPHERIC DENSITY ABOVE THE EARTH

Altitude (ft.)	Temperature ^{o}F	Pressure mm Hg.	Pressure p.s.i
0	59.000	759.99	14.696
5,000	41.174	632.38	12.228
10,000	23.355	522.75	10.108
20,000	-12.255	349.53	6.759
30,000	-47.831	226.13	4.373
40,000	-69.700	141.18	2.730
50,000	-69.700	87.488	1.692
60,000	-69.700	54.239	1.049
70,000	-69.700	33.640	6.505
80,000	-69.700	20.874	4.036
90,000	-57.204	13.033	2.520
100,000	-40.893	8.291	1.603
500,000	1473.000	3.7×10^{-6}	$7-2 \times 10^{-8}$
1,000,000	2104.000	1.8×10^{-7}	3.4×10^{-9}
2,000,000	2604.000	3.6×10^{-9}	6.9×10^{-11}

moon which allows most gases to achieve escape velocity.

3. Temperature

The lack of a lunar atmosphere contributes to an extreme thermal environment on the moon. While minor differences in temperature estimates exist, it is generally agreed that the temperature can range from a high of +215 to +266 degrees F at the height of the lunar day, to -240 to -250 degrees F during the lunar night (Branley, 1966; Whitaker, 1961; Strughold, 1962; and Roth, 1966). The range of temperatures recorded on the moon during one lunar day is depicted in Figure 2.

The range of temperature at a given point on the surface over a lunar day (27.3 earth days) far exceeds the range found at any point on earth. On earth, temperature changes of 30 degrees F in a 24 hours period, or even 50 degrees F in a 27 day period, do occur. On the moon, however, there is a change of approximately 465 degrees F in the 27.3 day-time period, or a little more than 1 degree F per hour.

Because of the earth's atmosphere, temperature changes between sunlight and shadowed areas are relatively small, with any changes in excess of 30 degrees F considered unusual. On the moon, however, while it can be 215 degrees F in full sunlight, the temperature can drop to below -200 degrees F in adjacent areas of deep shade. During the eclipse of 1927, temperature measurements of a limited area of the lunar surface

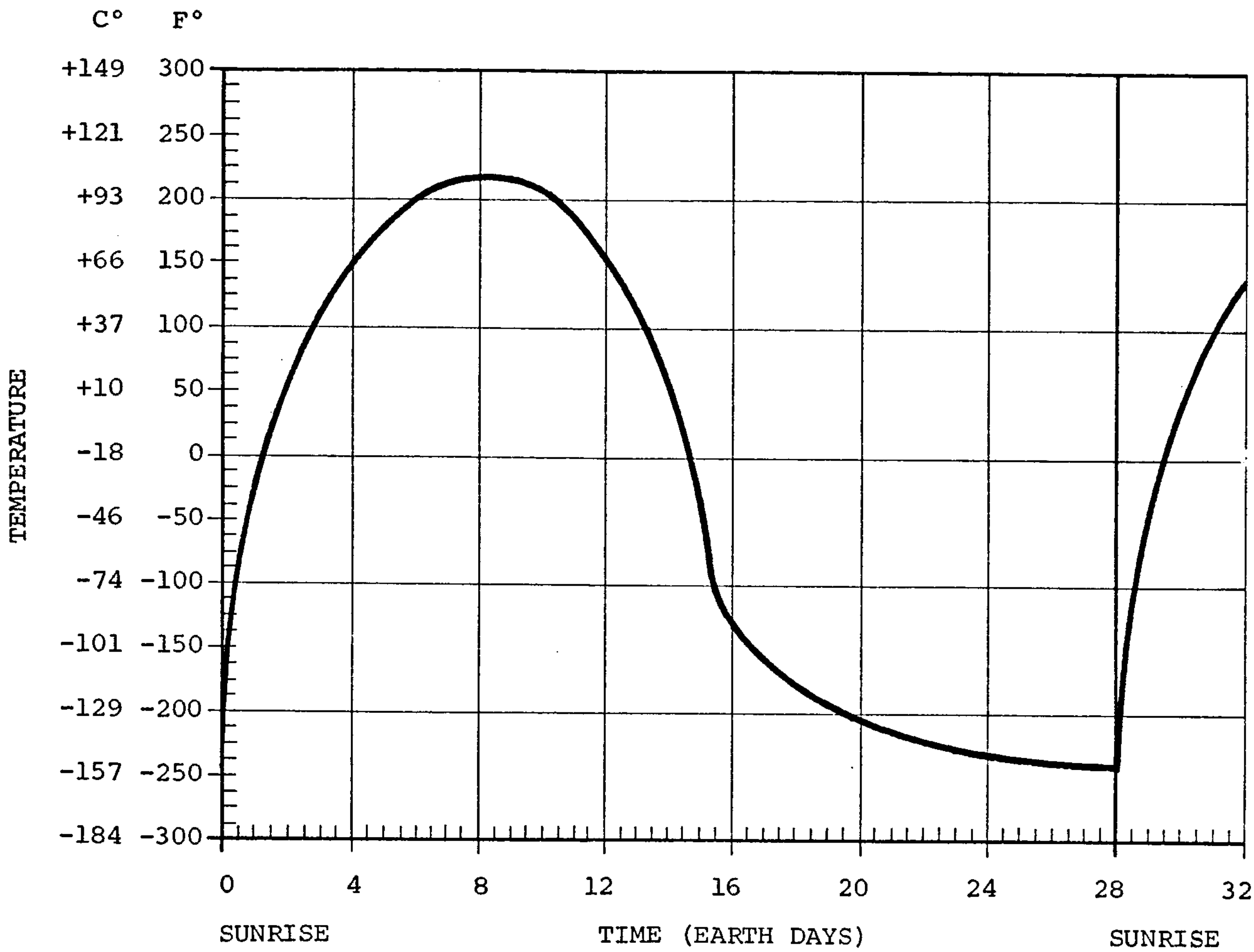

Figure 2 AVERAGE TEMPERATURE VARIATIONS AT THE LUNAR SURFACE. (from Branley, 1966)

indicated a pre-eclipse temperature of +156 degrees F. During the first hour of the eclipse, the temperature fell to -81 degrees F and 3 3/4 hours after the beginning of the eclipse, the temperature reached its lowest point of -186 degrees F. Shortly after the eclipse terminated, the temperature was in excess of 100 degrees F. Subsequent recordings under similar conditions indicated that such temperature changes were not the result of spurious readings or faulty recording techniques, but do in fact occur. These significant temperature drops indicate low heat conducting of the lunar soil. The thermal conductivity coefficient has been calculated at 3×10^{-6}, a coefficient comparable to that observed in dust in a vacuum (Gurshteyn, 1967).

A major difference between the earth and the moon regarding surface temperatures is that, on the moon, temperature is directly related to the amount of solar energy impinging upon an area at any given time period. On the earth, factors such as the atmosphere tend to stabilize the temperature so that changes are slight and less dramatic.

Although the surface temperature exhibits these extremes, analysis of the spectral radiation of the moon indicates that as little as 1 to 2 feet below the lunar surface, man may find a relatively narrow and constant temperature range of between -10 degrees F and -30 degrees F. Scientists believe that conduction of heat from the core of the moon (which has a temperature of 1,000 to 2,000 degrees C) accounts for this relatively stable temperature. Some also theorize that although there is no surface water on the moon, there is evidence for sub-surface glaciers (Kopal, 1964), or a layer of frozen water at a depth of approximately 30 meters (Strughold, 1962).

4. Topography of the Lunar Surface

Surface structure

There is much disagreement today among scientists as to the exact nature and cohesiveness of the lunar surface and whether the surface features have resulted from volcanic activity or meteoroid impact. Hapke (1956) stated that due to micro-meteorite impact the lunar surface has been pulverized to a high degree and probably has the consistency of baking flour. Hibbs (1967) agreed that at least the very top of the lunar surface must be covered with a fine powder.

On the basis of computations derived from panorama photographs of Luna IX, Gurshteyn (1967) concluded that the surface of the moon is solid and that its mechanical properties are granular. He did concede that the possibility exists that above the solid soil there exists a surface layer two (2) to three (3) cm thick which adheres together but which is less solid than the surface layer. Another Russian investigator (Avramchuk, 1966) stated flatly that no dust is present on the moon, even at the very surface. It was this author's opinion that the surface material is solid porous.

From a study of the photometric qualities of the lunar surface, Hapke (1967) concluded that the surface must be so rough that the micro-relief has little dependence on local directions of horizontal and vertical. Further conclusions based on photometric and polarimetric analyses state that the entire lunar surface has the same micro-relief, that the micro-relief is very porous and inter-connected, that the constituent particles of the micro-relief are uniformly fine, of the order or microns, and the the cohesion among particles is slight. The porosity of the surface is so great that the covering layer consists largely of a void with only about 25 percent of the volume occupied with scattered particles (Pearse, 1963, Hapke, 1967). Hapke (1967) summarized his position by concluding that the moon is covered to an unknown depth by a layer of rock dust whose particles have an average size of ten (10) microns (ten-thousands of a millimeter). These grains are arranged by micrometeorite bombardment into a porous material with a density of one-tenth that of solid rock, which arrangement he had earlier called "fairy-castles". Based on later investigation he concluded that the moon is not porous to the extreme extent that he originally suggested and does not have the extremely under dense fairy-castle structure, but rather consists of loose clumps of fine particiles which themselves have a porosity of eighty (80) percent and not ninety (90) percent as earlier assumed.

The powder is still very under dense and very compressive and if there were even a few feet of it an astronaut would sink to his knees and have difficulty churning his way through (Hapke, 1965). On the basis of simulation studies Hapke further concluded that finely divided powders are indeed capable of maintaining themselves in an under-dense state to considerable depths on the moon.

The case for a cohesive lunar surface was presented by Kohan (1960) and Halajian (1964). The former investigator assumed that the porous, vesicular substance of the lunar surface resembles in structure volcanic slag which originated from basic rocks, as a result of meteorite generated explorious (Kohan 1960). Halajian (1964) concluded that the lunar surface is constituted of a homogeneous, under-dense, cohesive material such as rock froth or furnace slag. It was his opinion that the roughness of the surface is not necessarily limited to the micro-scale (below 1 mm) since a macro-rough surface can match the lunar photometry. He further cites data indicating an increase in albedo with particle size reduction, which demonstrates the untenability of the dust theory due to the incompatibility of fine dust with low albedo unless it is demonstrated that some mechanism could lead to darkening of rock dust without fusing it (Halajian, 1964).

Data acquired from Luna IX, Surveyor I, and Surveyor III, are in agreement that no pulverized dust layer existed in the vicinity of their respective landing sites. Data from Surveyor III indicated that the dry lunar soil has a consistency similar to wet sand on earth.

Surface features

As reported by Rogers and Vaughan (1964), the continents or highlands of the moon, which occupy sixty (60) percent of the visible surface, contain a great concentration of ringed plains and craters. The surface is extremely rough and made up almost entirely of slopes ranging from 5° to 25° and averaging at about 10°. The darker maria, or lunar seas, constitute the remaining four (4) percent of the hidden surface. Maria surfaces are flat and featureless with slopes averaging two (2) to three (3) degrees. While devoid of such features as mountains the maria do exhibit boulders ranging in size from three meters down to 10 cm and craters as large as 17 meters in diameter (Vaughan, 1967).

The predominant boundary between continents and maria is sharp and commonly marked by escarpements. Heights of these escarpements may vary from several hundred to several thousand meters (Rogers and Vaughan, 1964). On earth the height of land masses is measured with respect to sea level. Since no such reference is available on the moon, measurement of lunar topography is in terms of altitude above surrounding terrain. Using this relative altitude technique, mountain heights of 25,000 to 30,000 feet have been calculated. Since the diameter of the moon is only 27 percent that of earth, to be an equivalent height mountains on earth would have to be 100,000 feet above sea level.

Probably the most familiar lunar terrain feature is the crater. Craters have been observed with diameters up to 145 miles, while the smaller craters, with diameters ranging from three (3) meters to a few cm, cover about fifty (50) percent of the surface. The relationship of crater wall slope with diameter is presented in Table 2.

TABLE 2.

AVERAGE AND MAXIMUM SLOPE AS A FUNCTION OF CRATER DIAMETER (Woods and Erlanson, 1966)

	Crater Diameter (feet)		
	100	1,000	10,000
Average slope in degrees	30	24	16
Maximum slope in degrees	70	46	28

The two major theories for the origin of the craters on the moon are the volcanic and the meteoric. As described by Branley (1966), the volcanic theory holds that the craters are all that remains of once great volcanoes, which depressions on earth are termed calderas. Earth calderas and lunar craters are both marked by sloping outer walls that form the rim, steep inner walls, and a floor smooth in some cases and rough in others. The meteoric theory proposes that craters are the results of meteorite impact. In these craters, one would find layers of rubble, rock dust, and meteoric fragments forming a rugged surface over the rocks broken by original impact.

The implications of these theories affect the potential safety of the astronaut when it follows that adherence to the volcanic theory leads to the assumption that certain areas of the maria are subject to collapse due to the presence of vesicles and caverns. The meteorite impact theory presents little collapse hazard and assumes that the highland's sub-surface consists of broken rock overlaid by rubble and meteoric debris (Branley, 1966).

Reporting on his observations of the lunar surface located less than 70 miles from his Apollo VIII command module, astronaut James Lovell, on December 24, 1968, described the moon as looking like plaster of paris or greyish deep sand. Astronaut Lovell further reported that craters were rounded off with terraced walls, comprising six (6) or seven (7) terraces on the way down.

5. Lighting

One of the most striking characteristics of the lunar environment is the unique behavior of light. Due to laws of light reflection and diffusion, a sphere when illuminated in the earth environment will appear brighter near the center and progressively darker as the extreme edge (limb) is approached. At full moon, however, the distribution of brightness over the surface of the disk is nearly uniform. This peculiar property, lack of limb darkening, was described by Galileo,who assumed a very rough micro-structure and macro-structure of the lunar surface,as the causal factor for the property. A second, related, photometric property of the moon is that the brightness of all parts on the disk increases up to full-moon and decreases after full-moon regardless of the position of the points on the disk (Roth, 1966, Pearse, 1963). Hapke (1965, 1967) stated that the manner in which the brightness of a lunar region varies during a lunation depends almost exclusively on the phase angle, the angle between the source of illumination and the observer. A third unique characteristic of the light environment of the moon is the backscattering or retro-reflection effect wherein most of the light reflected by the surface is reflected back along the angle of incidence.

A clearer understanding of these properties and their relationships will be obtained by considering three aspects of lunar lighting: illumination or incident light from the sun or sunlit earth falling on the moon; reflectance of the lunar surface or albedo; and luminance or brightness of the surface itself. These three aspects are related such that the brightness of the surface is a direct function of the reflectance and illumination: $B = EP$ where B is the luminance or brightness of the surface, E is the illumination, P is the albedo.

Illumination

The intensity of the sunlight falling on the moon has been calculated from 12,700 to 13,000 feet candles or 13.4×10^4 lumens per square meter (lux). This is approximately 1.4 times the illumination of the earth by the sun, the difference being due largely to the earth's atmosphere which allows less sunlight to impinge directly on the surface. Since the moon has little atmosphere much more incident sunlight is transmitted to the surface. The sunlight illumination itself is termed the solar constant and has been calculated at 1.2×10^4 foot candles.

The second major source of illumination of the moon is the sunlit earth. Full earthshine, which is the primary source of illumination of the new moon, has been calculated to be about 1.25 foot candles (Roth and Finkelstein, 1968; Lewis and Wheelwright, 1965; and Eggleston, 1962). A comparison of the solar constant and full earthshine, in different units, is presented in Table 3.

TABLE 3.

SOLAR CONSTANT AND FULL EARTHSHINE

Units	Solar Constant	Full Earthshine	Full Moon On Earth
lumens/m^2 (lux)	13.4×10^4	13.5	2.26
Ft. candles	1.2×10^4	1.25	.021
cal/cm^2/min	2.0		

As indicated in this table, the illumination provided by the sun exceeds that of the sunlit earth, perceived from the moon, by four log units while the illumination derived from the sunlit earth is greater by a factor of six (6) than that of the sunlit moon as seen from earth.

While approximately 134,000 lux from the sun are incident on the moon, only about 100,000 solar lux actually impinge on earth. This difference is largely due to atmospheric absorption and scattering whereby less light is transmitted through the earth's atmosphere to the surface.

Albedo

Albedo is generally defined as the percentage of total illumination of a planet which is reflected from its surface. Woods and Erlanson (1966) present two (2) types of albedo - local and spherical. Local albedo is the ratio of brightness of a diffusing surface to the brightness of an absolutely white surface placed normal to the rays of the sun. Spherical albedo is defined as the ratio between the light of the sun scattered in all directions by a hemisphere to the total light falling on the hemisphere. Values for local and spherical lunar albedos presented in Table 4 are from Woods and Erlanson (1966), NASA (1963), Gurshteyn (1967), Vaughan (1967), Schurmeier et al. (1966), and Herriman et al. (1963).

The low albedo of the moon, reported by Schurmeier et al. (1966) to be about the reflectivity of dark slate, was reported by Hapke (1965) to have been caused by a darkening of individual surface particles by the solar wind. Ions from the wind impact with particles causing particle atoms to become disengaged. On the assumption that the moon is composed of a silicate rock material, these free atoms will consist of oxygen, silicon and various metals. Due to the complexity of the surface, many disengaged

TABLE 4.

SPHERICAL AND LOCAL LUNAR ALBEDOS

Local Albedo -	Feature	Average Albedo	Range
	Maria	.066	.05 to .1
	Paludes (marshes)	.092	.09 to .1
	Continents	.105	.08 to .12
	Craters	.112	.06 to .18
	Aristarchus	.176	
	Sinus medii	.054	
	Smooth rays		.088 to .096
	Rough rays		.096 to .114
	Bright rays	.131 or .140	.10 to .16
Spherical Albedo		.073	

atoms adhere to the undersides of adjacent rock particles. Since oxygen is more volatile, it's atoms will have a lower sticking coefficient than the other atoms, hence, fewer oxygen atoms will adhere to the underside of the particles. This process results in a coating of a dark material on the underside of the rock particle, which is probably a nonstoichiometric silicate compound deficient in oxygen.

Brightness of the Lunar Surface

Since the average illumination of the lunar surface is 12,000 ft. candles and the average albedo .07, it follows that the average brightness of the surface is 840 ft. lamberts (B = EP). The average albedo for maria is .066 while for continents it is .105. Hence, the brightness averages for these areas is 800 ft. L. and 1200 ft. L. respectively. Due to the lack of atmospheric scattering, the deepest shadows will approach a luminance of 10^{-6} ft. L., while the brightness level of full earthshine approximates 1 ft. L (Roth, 1968). The relationship of these lunar brightness figures to earth standards is apparent from Figure 3. As indicated by this figure, 1000 ft. L. approximates the brightness of the average earth on a clear day while 10^{-6} ft. L. represents the absolute threshold for seeing.

As indicated earlier, the maximum brightness of the moon taken as a whole is achieved at full moon, when the source is directly behind the observer; that is, the sun directly behind the earth. The lunar brightness decreases sharply as the phase angle increases from zero degrees (full moon). The phase angle is defined as the angle at the moon between the directions of the earth and the sun. This dependence of brightness on phase angle holds true for all portions of the lunar disk and the maximum brightness of all regions occurs at the smallest phase angle. The relationship of brightness with phase angle is depicted in Figure 4. As indicated by this figure, the surface brightness of the moon falls off by approximately 50 percent when the phase angle is increased from zero to 30 degrees.

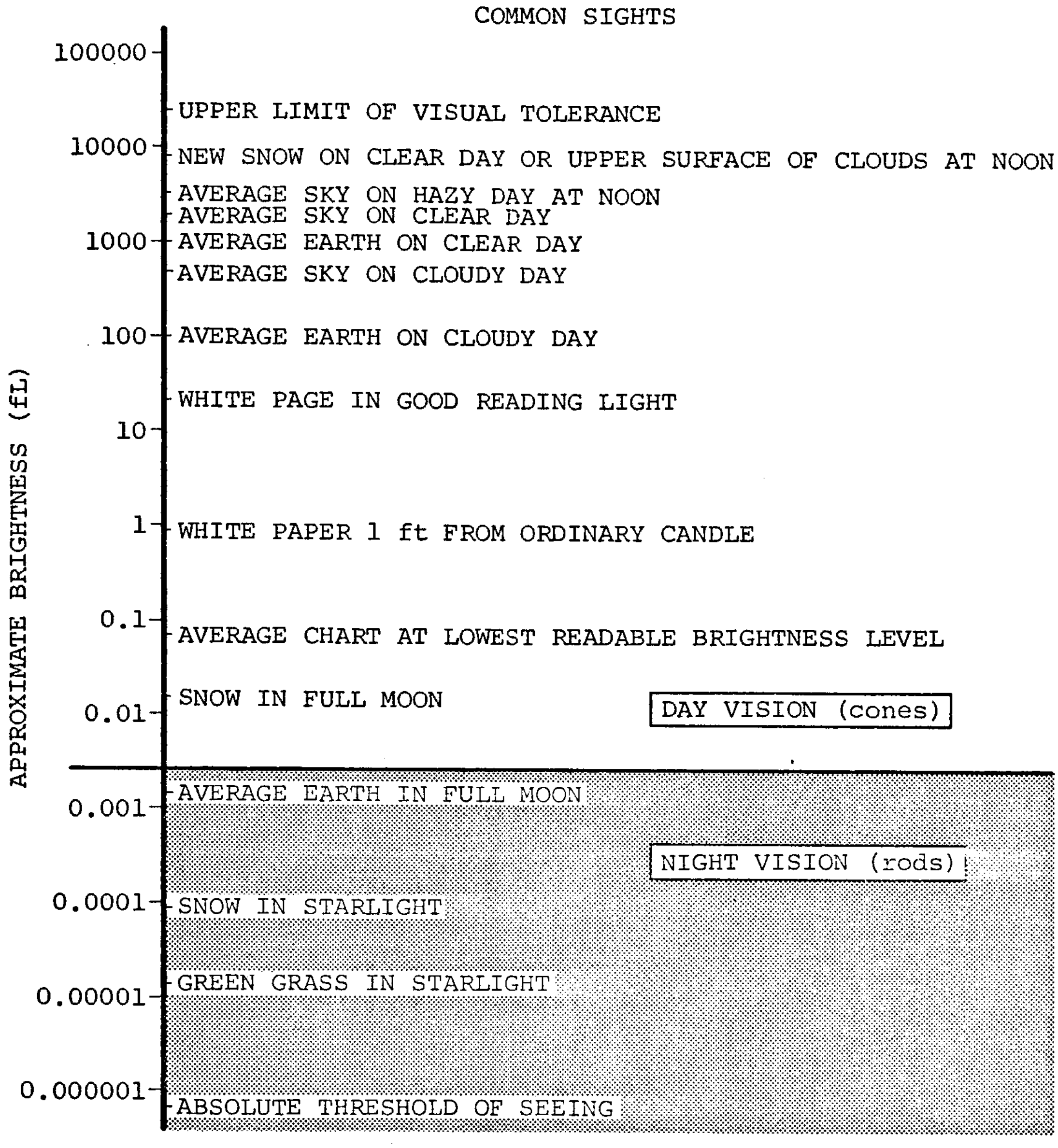

Figure 3 BRIGHTNESS STANDARDS. (from Morgan, et al, 1963)

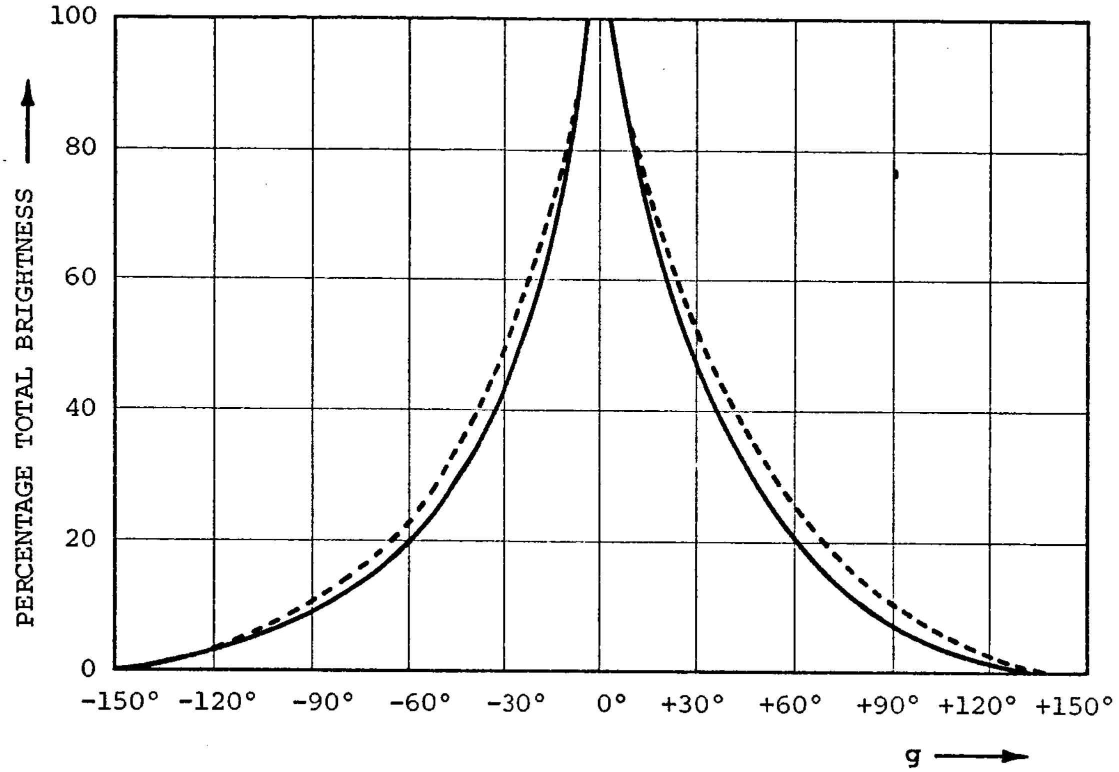

Figure 4 THE TOTAL BRIGHTNESS OF THE MOON AS A FUNCTION OF THE PHASE ANGLE, g. AFTER ROUGIER (Full Line) AND RUSSELL (Dashed Line). (from Pearse, 1963)

From the above, it is obvious that the most important determiner of lunar brightness is, within limits, the geometric relationship between the observer (earth) and the source (sun). The fact that the moon achieves its maximum brightness when the source is located directly behind the observer emphasizes the fact that reflection of light on the moon is different than commonly encountered on earth. Most reflectance on earth is specular wherein the angle of reflected light is equal and opposite to the angle of incidence. A second type of reflectivity encountered on earth is diffuse reflection where light is reflected equally in all directions regardless of the angle of incidence. The lunar surface, however, is marked by its retro-reflection of light wherein the maximum amount of light is always reflected in the direction of the illumination source. This accounts for the situation where the moon is brightest when the angle to the source (sun) equals the angle to the observer (earth), as in the full-moon.

As indicated above, the brightness of the lunar surface (B) is a direct function of the illumination (E) and the albedo (P). This equation, $B = EP$, actually describes the brightness of the moon only at zero phase angle or full-moon. The luminance of any lunar region at any phase angle other than zero is $B = EP\,\phi$, where ϕ is a normalized, dimensionless function of the geometry of the illumination and viewing situation (Herriman et al., 1963). This is the photometric function of a surface and is characteristic of the surface structure itself. This function has been normalized to unity for other angles. The photometric function for a given surface is described in terms of three variables, the angle of incidence of the impinging light, the angle of observation, and the phase angle or angle between these two. For any phase angle, the value of the photometric function does not vary appreciably along a given luminance meridian, hence, ϕ is a function of the phase angle (g) and the luminance meridian or longitude (a). The geometry of these values is depicted in figures 5 and 6. As indicated in figure 6, "a" defines the luminance longitude, and varies $\pm$ 90 degrees to the limb. As "a" is measured away from "s", the sub-solar point, the sign is positive, while as "a" is measured toward "s", the sign is negative. The photometric function, as a function of phase angle "g" and "a", is depicted in figures 7 and 8 (Herriman et al., 1963).

As observed by Gurshteyn (1967) the photometric data definitely point to a rough, broken micro-relief of the lunar surface whose individual irregularities greatly exceed the wavelength of light. This conclusion was agreed to by Hapke (1967), who noted that the independence of the lunar reflection law on the orientation of the local surface implies a surface so rough that the micro-relief has little dependence on local directions of horizontal and vertical. To back-scatter light as strongly as it does, the moon must have not only an extremely porous and open structure but the cavities in the surface must also be interconnected. The explanation for the back-scattering or retro-reflection is given

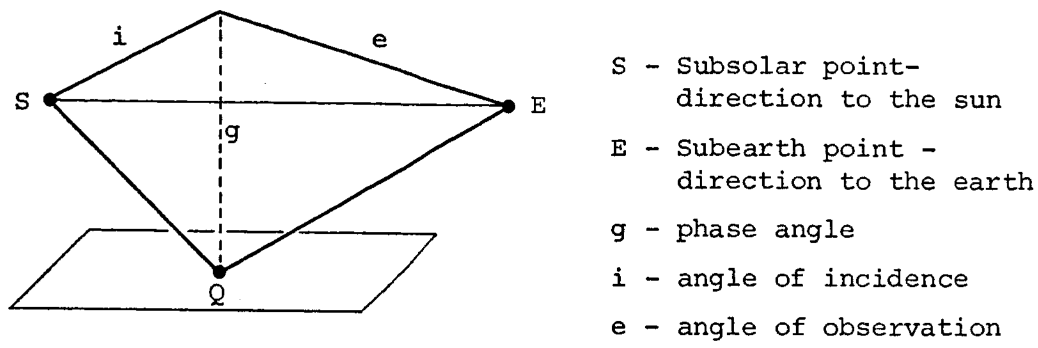

Figure 5. ILLUMINATION AND VIEWING GEOMETRY

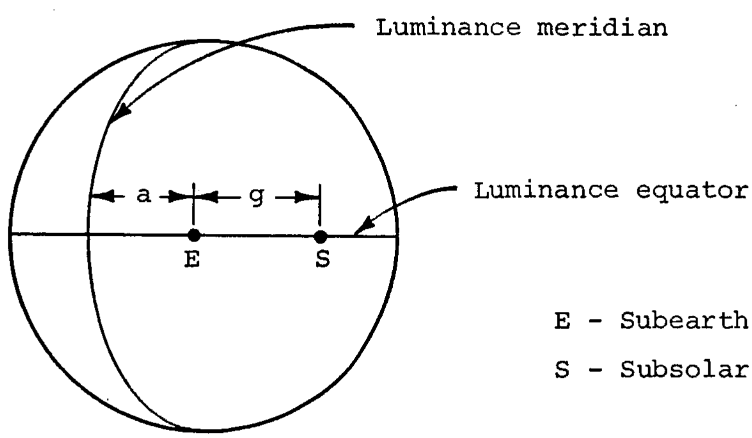

Figure 6. RELATIONSHIPS OF a AND g

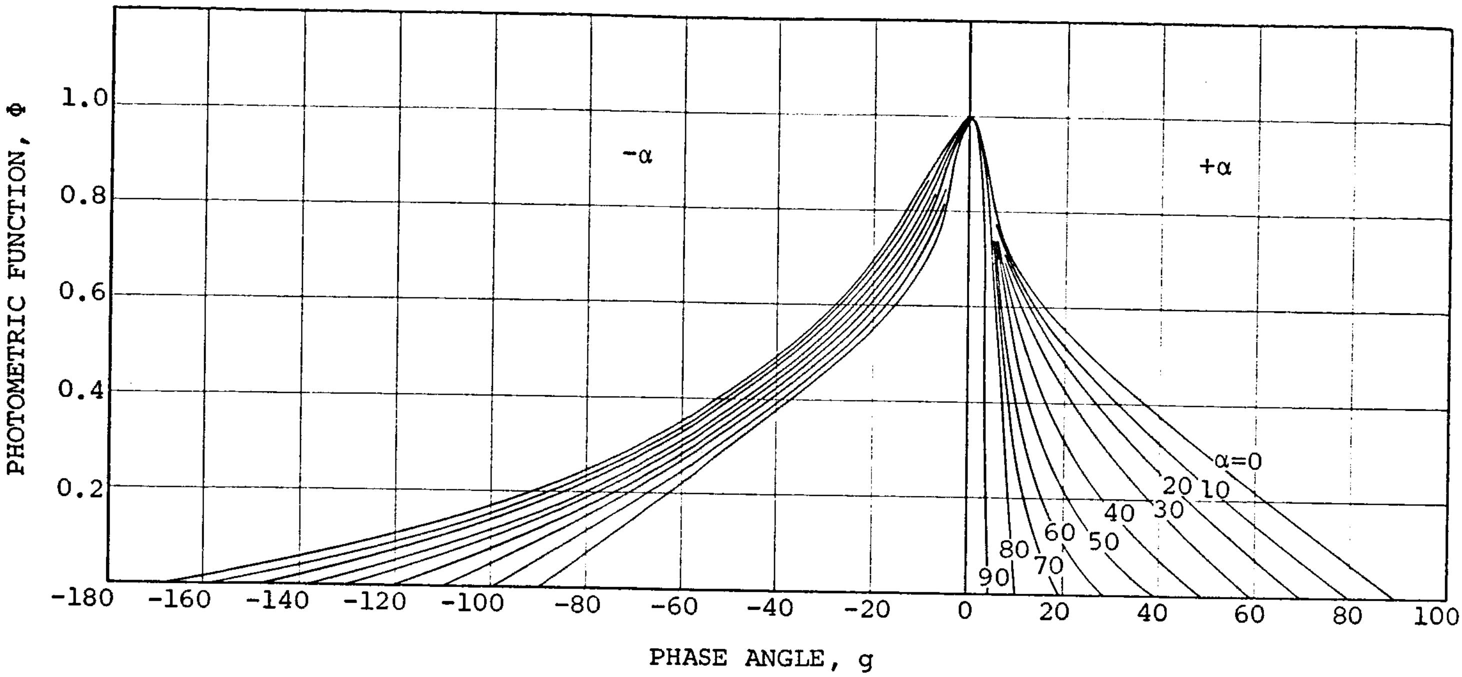

Figure 7 THE PHOTOMETRIC FUNCTION vs g.

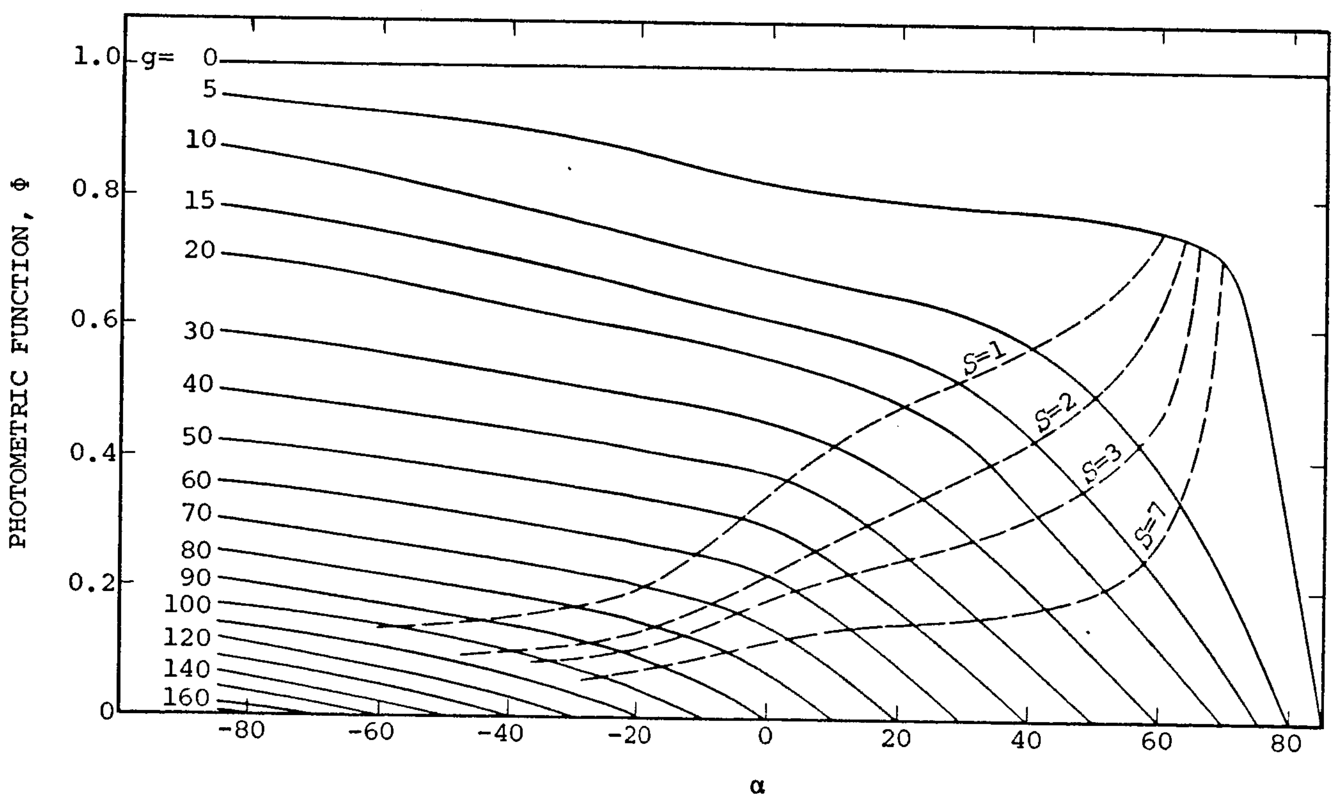

Figure 8 THE PHOTOMETRIC FUNCTION vs α.

by Hapke (1967) as follows:

> Light can penetrate into a surface freely from any direction and will partially illuminate objects under the surface. Light rays reflected directly back toward the source from deeper objects can escape unattenuated along the path of incident radiation, but rays reflected from deep objects in any other direction are partially blocked and absorbed. Therefore, the brightness of the surface is greatly enhanced when the surface is viewed parallel to the direction of illuminance.

6. Invisible radiation

The lunar surface is continuously bombarded by radiation outside the visible spectrum. This radiation comes from two major sources, galactic cosmic radiation, originating outside of our solar system, and solar cosmic rays.

Galactic cosmic rays are believed to be elements found in our universe that have been ionized and then accelerated to fantastic speeds. The component aspects of galactic cosmic rays are very similar to the composition proportions of our universe. The primary particles of the rays are actually charged atomic nuclei. These rays have a flux of particles in the order of magnitude of $2.5/cm^2/sec$.

Galactic rays may be considered in two groups. Protons and helium constitute the lighter group, while all remaining elements constitute the heavy group. The kinetic energy of galactic radiation varies from 100 million electron volts (mev) to several billion electron volts (bev) per nucleon. The high energy galactic rays are not readily attenuated by matter. When primary particles interact with other matter, secondary radiations result in the formation of electrons, mesons, gamma rays, and neutrons.

Cosmic radiation of galactic origin is omni directional as observed from earth, and the intensity of this radiation measured on the earth exhibits a regular periodicity of eleven (11) years. This is considered to be due to the magnetic activity of the sun environment associated with its approximate eleven (11) year sun spot cycles (Kekhuis, 1962).

While their energy is great, it is generally concluded that primary cosmic particles are not dense enough to deliver a serious radiation dose.

Solar cosmic radiation is the result of the emission of particles from the sun. With increased activity on the sun, such as sun spots, there are correlated increases in solar radiation. With the advent of a solar flare, which is a large chromospheric eruption on the surface of the sun, usually associated with sun spot activity, the density and intensity of solar radiation increases markedly. Such flares send forth great quantities of particulate matter and energy from the sun at velocities in excess of 500 km/sec. and will represent the dominant radiation hazard to astronauts (Whitaker, 1961). These flares may be present on the surface of the sun for over three (3) hours. As was stated earlier, this activity seems to follow an eleven (11) year cycle. The particles emitted have energies ranging from 3 to more than 500 mev. Protons and electrons emitted by a large flare will reach the moon in thirty (30) minutes. Following their arrival, the intensity increases for about an hour, then decreases (Whitaker, 1961). Coronal particles from the sun comprise the solar wind. These particles are electrically charged and travel at several hundred miles per hour (Henry, 1966). The radioactivity of the lunar surface has been the subject of some speculation. Data obtained from the Luna 10 Gamma Ray Spectrometer indicated that the radioactivity of surface material was less than that of terrestrial granite.

CHAPTER III.

LUNAR MISSIONS, EQUIPMENT, AND OPERATIONS

Exploration is a process of steadily building on prior experience. Much is known already of man's physiological, psychological, and psychophysical reactions, both on earth and in orbit. Astronomers and scientific laboratories have done extensive work on defining the characteristics of the lunar surface and environment. A variety of suits and hardware configurations have been developed and tested via simulations and space flight. Yet, when one examines the many facets of manned lunar surface operations and tries to evaluate our readiness to make this step, many questions arise that have no precise answers. Since we are forced to extrapolate along many lines from presently available knowledge, many answers are hypothetical. In some cases authorities are able to put forth logically and scientifically sound arguments for contradictory viewpoints. The resolution of many questions that need answers together with some which may even have been raised, must await the return of data from the early lunar landings.

This report will attempt to identify and deal with as many of the definable performance problems of lunar surface exploration as possible. The natural source of data for this analysis would be the mission profile containing the activities and actions expected of astronauts on various missions. Although a great many scientific and system related objectives have been proposed, very little information exists on how the data to meet these objectives will be collected.

Planning of lunar surface activities is vital not only in determining astronaut performance requirements, but to estimate the volume of data desired by scientists, together with the analytic support required. Present man power needs appear to be well beyond our current resources. The magnitude of this effort was investigated by North American Aviation (1966), using the transcripts of previous summer conferences on lunar exploration as source documents.

This study concluded: "...if the assumption is made that, for each astronaut, 8 of every 24 hours is used for the performance of experiments on the lunar surface, approximately 4790 man-days (Earth days) would be required on the lunar surface to perform each experiment once. If it is assumed that three men will be on the lunar surface during the extended phases of lunar exploration, approximately four years elapsed time would be required for the extended exploration phase, assuming continous lunar surface operation....the most critical problem can be the lack of scientists for analysis of Earth return data... A deficiency of approximately 9,000 man-years of scientific work is forecast to be accrued by the transition phase between early and extended lunar exploration."

These estimates are based on some 340 identified experiments with little firm data on specific performance requirements.

An attempt could be made to identify and itemize the astronaut perceptual and motor capabilities required to perform each of these experiments. Considering the overlap to be expected, this does not seem an effective method to compile a list of performance requirements.

Descriptions of lunar missions, experiment equipment, and astronaut operations for types of missions are presented in the following sections. Mission requirements and operational requirements will be evaluated in terms of the information presented in the next chapter "Research on Human Performance in the Lunar Environment", to develop potential problem areas for human performance.

As specified by the Santa Cruz conference on Lunar Science and Exploration (1967) the primary scientific objectives of early Apollo, Apollo, and Apollo Applications Program (AAP) lunar missions are as follows:

- To determine the type, form, structure, distribution and age of material masses.
- To determine the physical, chemical, mineralogical, and petrogenetic nature of materials.
- To observe endogenetic (volcanism) and exogenetic (meteorite impact, solar wind) processes.
- To interpret crustal features.
- To develop a comprehensive geological history.

3.1 Manned Lunar Missions

The scientific objectives for lunar missions are usually organized into eight disciplines or areas. These are:

Geodesy/cartography
Geology
Geophysics
Geochemistry
Astronomy
Bioscience
Lunar Atmosphere Measurement
Particles and Fields

Lunar surface data collection for each discipline depends, to various degrees, on man's unique capabilities. The general task requirement for each discipline area have been spelled out in some detail at the two summer conferences. The differing need to have man performing can be pointed out by examining the areas outlined below.

a) Geodesy/Cartography

The purpose of this discipline is the development of accurate geodetic, navigational, and cartographic material. Considering the size of the moon, it is not feasible to collect this information on the surface. The primary data will be assembled by a system of lunar orbital missions with surface operations being used to refine the accuracy of orbital measurements and emplace surface equipment in support of Earth based and orbital programs.

b) Geology

The initial objective will be the study of the fine structure of the lunar surface, mainly in the mare, to determine the nature and origin of underlying materials. Later, a series of traverses will be taken to observe, collect samples, and to report on the geological characteristics of large areas.

These tasks are dependent on man's physical presence on the lunar surface and the skill, knowledge, and judgment that he brings to the job.

c) Geophysics

The problem of geophysical exploration of the moon has been stated to include study of the present state, structure, and composition of the moon and to infer the history and origin of the moon.

d) Geochemistry

The most significant and meaningful results expected from manned exploration of the moon will be derived from samples of lunar materials returned to earth. Measurements of these samples will produce insights on composition of the surface and establish the limits on the extent to which wide scale chemical and mineralogical measures made on the surface will serve to establish the variability of materials at a given site.

e) Astronomy

Radio, X-ray, and gamma ray astronomy require observations which probably can be made better on the moon than any other place. For the latter two techniques the moon offers an extremely stable platform with a slow rotation rate and a distant horizon to serve as an occulting edge.

f) Bioscience

The primary interest will be in the collection, return, and detailed investigation of lunar samples for biochemically important compounds or organized elements.

g) Lunar Atmosphere Measurement

Knowledge of the density and composition of the lunar atmosphere should provide valuable information concerning the lunar interior chemistry and radioactivity, possible volcanic process, and chemical and isotopic compositions of solar wind.

h) Particles and Fields

Objectives of experiments will be directed at increasing the current body of knowledge concerning magnetic fields, electric fields, low-energy charged particles, plasma, and solar and galactic cosmic-ray experiments.

To organize the diverse manned activities into a coherent structure, a three-stage model of exploration and exploitation is proposed. While the model is general, it serves to focus on the key factors that influence missions design and organization.

Stage I includes the Apollo and early Apollo missions, the first lunar visits, lasting from a few hours to a few days. It is characterized by an emphasis on verifying the adequacy of system hardware and procedures, which will limit the amount of time and material available for scientific activities. Astronauts will depend on their landing vehicle for shelter and supplies and their legs for locomotion. The data collected on man's adequacy in, and adaptability to, the lunar environment as well as the data on system hardware used during these missions will provide the basis for planning of advanced missions. By the end of this stage, we will have much more confidence in our ability to safely proceed with exploration.

Stage II includes the missions of the Apollo Applications Program (AAP), and is characterized by the greatly expanded capacity of astronauts to remain on the Moon and to move about its surface. Stay time will range from several days to six months. Locomotion in lunar vehicles, both surface and flying, will allow travel of hundreds of miles. A high percentage of surface activity will be devoted to scientific purposes.

Manned surface operations, from this point on, may be dichotomized into fixed site activities (similar to stage I activities) and those tasks associated with performing in the "field". These types of operations might be further organized as follows:

a) Fixed site operations

   (1) Moon-oriented activities such as drilling or laboratory studies.

   (2) Moon based activities such as setting up and operating various types of astronomical observatories.

   (3) Habitation activities having to do with maintenance, logistics, and life support.

b) Traverse operations

   (1) Ground vehicles provide a mobile site for investigating features of interest within 50 miles of the fixed site.

(2) Flying vehicles can serve many functions such as:

- rapid deployment of equipment
- access to sites not accessible by surface travel
- a real reconnaissance for mapping or monitoring the progress of surface traverse operations.

Although hardware may be expected to have continued its development toward flexible, reliable systems, man's adaptability may limit the length of a mission. Stay time will be steadily increased, as in our Earth orbital programs, as information demonstrating a satisfactory adjustment to the unusual lunar conditions is collected.

The AAP missions probably will involve multiple payload landings, however, early missions requiring stays of only one or two weeks, may be confined to a single vehicle. For later missions, unmanned logistic vehicles, specially adapted for this function, will deposit scientific instruments, roving vehicles, and consumable supplies near the astronauts' temporary base. This technique allows prolonged stays, if necessary, to meet scientific objectives. It also points out the dependence of lunar explorers on Earth for all their supply needs.

Stage III begins the development and exploitation of the Moon for specific scientific and economic purposes. A permanent observatory, with optical and radio telescope, free of Earth's distorting and filtering environment, is a well-known scientific use of the Moon. Mining of water on the moon would be typical economic enterprise. The water and its by-products, hydrogen for refueling space ships and oxygen as a space ship and lunar life support supply, would be readily available to our space program at a far lower cost than if Earth supply were continued. The supplied water, hydrogen and oxygen, as well as the minerals that may be available on the moon, will permit lunar bases to be relatively self-sufficient.

Certainly, many of the same basic human performance capabilities are required at some time during all these missions. Astronauts will have to be able to walk on the surface from the first lunar landing to the last. However, a certain function of increasing complexity is implied by the model. The discussion of Stage I and Stage II missions will focus, therefore, on the additional burden placed on the astronauts from stage to stage. Stage III missions will not be considered since mission details and objectives are uncertain at this time. It can be assumed that many astronaut activities of Stage III missions will be performed on Stage I or II missions, hence the examination of these long duration missions is not likely to add much to the assessment of astronaut performance.

3.1.1 Stage I Missions

This stage is characterized by short stay time, limited mobility, and an emphasis on gaining confidence in the systems and procedures needed to carry on lunar surface activities. Two men will spend from about 3 daylight hours at selected landing sites, to a full earth day. The Lunar Module (LM) will perform lunar landing, provide shelter, and return the crew to orbit for rendezvous and return to Earth. Each crew member may spend several hours outside the LM performing inspections, setting up equipment, and performing simple scientific tasks. No activity will require going more than a few hundred yards from the point of touch down. This should insure that there is a line of sight path between the astronauts and the LM vehicle at all times. Current thinking tends toward the philosophy of allowing only one man to work on the surface at a time. This may well be the case throughout Stage I, until sufficient data have been collected on systems and human capabilities to evaluate the advantages and risks involved in two-man surface operations.

Since the first lunar landing will be considerably less demanding on the astronauts that subsequent missions, it will be discussed separately and in some detail. The remaining Apollo missions will be discussed in more general terms to emphasize the primary areas requiring astronaut interaction.

A) <u>The First Manned Landing - Early Apollo</u>

The first stay on the moon will last about three hours. One astronaut will spend about two hours working on the surface while the second remains aboard the LM, monitoring systems status and maintaining the communications link. The surface activities will involve the following:

1) Ingress and egress of the LM vehicle

2) Standing and walking on the lunar surface

3) Vehicle inspection

4) Deployment of the Early Apollo Scientific Experimental Payload (EASEP)

5) Collecting surface samples

Originally, the tasks on the first landing had been patterned after the rest of the Apollo missions. However, this being the first chance to perform on the surface, little could be said of the burden any specific activity would place on the astronaut. The initial Extra-vehicular experience from Gemini demonstrated that even relatively simple tasks were extremely difficult to perform in a new gravity environment regardless of the pre-experience training. Therefore, in the interest of crew safety, the scope of this mission has been reduced. The data to be obtained from the samples of surface performance will be of inestimable value in planning future missions.

Two of the tasks involved in this mission are representative of activities that run throughout lunar exploration. These are the surface sampling and the deployment of EASEP. Geological activities will be discussed more fully under the Apollo missions. EASEP, the beginning of a long line of similar tasks, is detailed in this section.

EASEP represents the simplest configuration of a whole host of experimental packages that will eventually be sited at many locations around the lunar surface to provide a steady source of Geophysical data. The concept employs modular experiments that will be supported by a central power and telemetry station. The remaining Apollo missions will expand EASEP to the full Apollo Lunar Surface Experiments Package, (ALSEP). Later missions (Stage II) will deploy various ALSEP configurations around central units called Emplaced Scientific Stations, (ESS).

B) Apollo Missions

The Apollo missions involve two astronauts landing on the lunar surface in the lunar module (LM), and staying for approximately twenty four hours. Surface activities will occupy as much as eight hours for each crew member. These missions, although still emphasizing the qualification of lunar systems and procedures, begin the actual exploration of the moon. The scientific objectives of these missions is to initiate the development of a data base of scientific knowledge about both the moon and man's ability to perform in this unusual environment.

Fixed-site studies, the only type for these missions, fall into the major categories of Geology and Geophysics. The latter, involves the development of the ALSEP experiment in the vicinity of the LM. An S-band antenna will be erected and left on the surface to permit telemetry of data from experimental modules after the crew has left the site. Theodolite observations may be made to help in the precise determination of specific locations in this area.

The Geology Working Group at the 1965 NASA Summer Conference on Lunar Exploration and Science described the types of activities to be expected, some of the reasons for these activities, and the importance of having an astronaut involved in the data and sample collection process. They said:

> "The principal geological objectives of early Apollo missions will be study of the fine structure of the lunar surface, mainly in the plains areas favorable for early landing, and study of the nature of the plains materials. These plains are depositional surfaces, modified by postdepositional processes of several kinds. In the limited time available for geological investigation in the early Apollo missions, the two primary questions to be answered will be (1) the lithologic composition, structure, and thickness of the superficial layer of fragmental material believed to cover most parts of the plains and other areas on the Moon and (2) the composition and origin of the material underlying the plains.
>
> There is a good chance that the samples obtainable in a small area on the lunar surface that can be investigated by the astronauts in an early Apollo landing may contain information not only about the local part of the Moon on which the landing takes place but also about a much wider region. The reason for this is that many rock fragments on any part of the Moon's surface probably have been derived from distant parts of the Moon. It will be important, therefore, to conduct sampling in such a way as not to overlook any of the exotic pieces that may be present. The samples taken should provide information both on the local rock material that underlies the plains and also on the petrologic heterogeneity of the Moon.
>
> Descriptions of topographic and geologic relations observed along the traverses of the astronauts should be supplemented by numerous stereoscopic photographs. The photographs provide a detailed record of the surface

features, which can later be analyzed quantitatively, and will provide the geologic context at the site of each sample locality. It will be important to record the orientation of the cameras during exposure of the photographs for use in later photogrammetric and photometric reduction of the photographic data."

The geological investigations described above fall into three categories:

a) Investigation of the geological characteristics of the landing site of specific areas of interest within walking distance.

b) Collection of rock and mineral samples for return to Earth. Sampling will have to be supported by detailed documentation so the source of materials can be re-established at a later date.

c) Simple field experiments such as measuring or estimating the effect of small disturbances on different types of surface material.

The technique used to obtain samples will depend on the judgment, equipment and manipulative capabilities of a suited astronaut. Based on earth experience, it is fair to expect that sooner or later geological activities will require close examination of the surface and subsurface. Therefore, the suit must allow the astronaut to kneel and work on the ground with his hands. Specific surface tasks may include:

- Merely picking up various specimens
- Breaking off or coring out a piece of a larger structure
- Digging up surface samples of incoherent fragmental debris
- Drilling a shallow hole through incoherent fragmental debris
- Excavating and taking spot samples

During these Apollo missions much of the astronaut's time and energy will be directed toward deployment and actuation of ALSEP payloads. Weight of the ALSEP has been held to 210 lbs., limited by the size of the scientific equipment bay of the LM. The ALSEP is carried in two separate compartments in the bay. Subpackage 1 contains the central station with the sun shield mounted on the top. Subpackage 2 contains the radioisotope thermo electric generator (RTG), Apollo lunar hand tools, antenna-pointing mechanism, and supra-thermal ion-dector equipment. The power supply for ALSEP will be a SNAP 27 RTG which provides 67 watts for one year of operation. The experiments to be included in ALSEP include the following:

(1) Passive Seismic Experiment - to measure quakes, meteroid impacts, lunar tides and free oscillations

(2) Active Seismic Experiment - to measure lunar elasticity to about 500 feet

(3) Heart Flow experiment - including the Apollo Lunar Surface Drill - to measure interior temperature

(4) Cold Cathode Gage Experiment - to measure atmospheric pressure

(5) Supra-thermal Ion-Detector Experiment - to determine atmospheric composition

(6) Lunar surface magnetometer - magnetic downflux of solar wind

(7) Charged Particle Lunar Environment Experiment

(8) Solar wind spectrometer

3.1.2 Stage II (AAP Missions)

These missions cover lunar stays of from several days up to six months. Early crews will still be composed of two men, but more than a single crew may be operating on the surface at the same time. Later missions will have larger, more sophisticated delivery vehicles available permitting three-man crews to land. Fixed site activities will still be heavily geological, but significant efforts will be expended in the fields of astronomy, Space and Solar Physics, and Biology.

Characteristics of this stage include the capability of extended stays and great mobility, yet complete dependence on Earth for logistic support. Mission support will be primarily by means of slightly modified Apollo hardware. These modifications are based on specialized applications of the LM vehicle, and include the following:

a) The LM Taxi. This is an almost unaltered LM which will be used exclusively for shuttling to and from the lunar orbit. On the surface, it will remain in a stand-by state until needed.

b) The LM Truck. This is a LM modified to operate as an unmanned payload carrier. The placement of a lunar Roving Vehicle (LRV) onto the surface is one typical application of the Truck.

c) The LM Shelter. This is a LM vehicle modified to provide living and working quarters for the crew on the lunar surface. Since it does not need a lift-off capability, it is able to land with enough supplies to carry out this function for two weeks without re-supply.

The major supply method will be by a direct Saturn V flight from the Earth to the Moon. This procedure will allow the delivery of 15 tons of supplies and scientific equipment, far in excess of the amount deliverable in the usual lunar-orbital rendezvous (LOR) mode. This procedure permits exploration teams to stay many times longer than would be possible or economically feasible, using only the LM Truck.

Locomotion will be accomplished via various roving vehicles (LRV) and lunar flyers (LFV). One typical LRV is both a mobile living shelter and experimental station. It is capable of sustaining two men for a two-week exploratory mission. Flying vehicles of both the one-man and two-man type will be available for transportation and scientific purposes.

During these long stays, two important differences from the Stage I mission become apparent. First, the astronaut will be faced with night as well as day operations. Therefore, all types of lighting effects are certain to be encountered. The second difference is that equipment will not only be set up and operated, but must be maintained as well. This will bring a whole new series of performance and habitation requirements into focus.

Selection of regions in which to establish sites will be influenced by a number of factors, which include the concentration of significant geological features, and the accessibility to these with available systems. Twenty major types of features have been identified. These are:

1) Maria

2) Highlands

3) Copernican age craters

4) Erathosthenian age craters

5) Procellarian age craters

6) Imbrian age craters

7) Pre-Imbian age craters

8) Maar craters

9) Chain craters

10) Satellitic craters

11) Central peaks

12) Domes

13) Ray material

14) Rills

15) Wrinkle ridges

16) Fault scarps

17) Lineaments

18) Imbrian ejecta

19) Mare scarps

20) Bright hills with rays

The occurrence of high density areas, such as Kepler where as many as nineteen of the types lie within a fifty mile radius, will provide a great deal of data in relatively few landings. The key to success in these missions is the roving and flying vehicle and of course detailed planning. Route surveying, or accurate mapping, is vital to planning and interpretation of measurements. It appears unlikely that the surface positions for scientific field work could be pinpointed from photographs or maps. Thus, navigation and tracking will be critical problems from both the scientific and safety point of view.

The LSS should be sufficiently developed by this time to provide the necessary tracker-surveillance capability. The system is intended to track an astronaut on foot, or a vehicle, and will provide real-time monitoring.

Since stay time is expensive, each surface traverse must extract and collect as much information as possible. This implies the use of a large number of different scientific measurement and data recording devices, as well as the accurate deployment of Remote Geophysical Monitors (RGM's). The RGMs will provide a widely spaced net of seismometers, gravimeters, and transponders and will serve as outlying stations in a triangular - array configuration in conjunction with ESS or EXESS central station. The astronauts will be called upon to operate and deploy these pieces of equipment under less favorable conditions than found during Stage I. The data base on astronaut performance, acquired during Stage I, should permit equipment designers and planners to cope with the more demanding environment.

Fixed-site activities will be more ambitious. A drill capable of producing at least a 100-meter hole will be erected.

Explosive charges will be set off for active seismic measurements. Biological studies will be run on plants and animals (man included) to determine any long-term effects of reduced gravity, any changes in biological rhythms, and the genetic effects of radiation. Physics and Chemistry will be able to perform studies on ultra-high vacuums, cold temperatures, and primary rays. These may lay the ground work for whole technologies that will be based on the moon.

Astronomical observations on the moon, both optical and radio, have advantages over orbiting stations. Therefore, one of the AAP events will be the erection of an optical telescope on the LM Shelter.

As described by the Geophysic Group Report in the Santa Cruz Lunar Science and Exploration Study (1967), AAP will make use of emplaced stations to carry out observations on the lunar surface over extended periods of time. Examples of remote stations are the Emplaced Scientific Station (ESS), the Expanded ESS (EXESS), and the Remote Geophysical Monitor (RGM).

The Emplaced Scientific Station (ESS) represents the present ALSEP upgraded for longer life and improved performance. The ESS will serve as a central observatory and, for AAP, will be regarded as a major support system which can provide power and telemetry for any experiments or array of experiments. The candidate experiments for ESS include:

1) Passive seismic/tidal gravimeter/tiltmeter

2) Surface triaxial magnetometer

3) Heat flow

4) Active seismic

5) Dust transport monitor

6) Corner reflector

7) Micrometeoroid detector

8) Doppler transponder

9) Surface electrical field

10) Total pressure gage

11) Mass spectrometer

The expanded ESS (EXESS) will serve as a long lived observatory which can support a greater number of experiments than ESS. To the ESS experiments the EXESS would add a deep drill (100 feet) and a strain meter.

The Remote Geophysical Monitor represents a conceptually new system for delivering from 8 to 12 lightweight geophysical stations to the surface from an orbiting CSM or from an automated LSSM, with impact loads of 25 g or less. These methods of deployment appear to be particularly convenient to achieve a widely spaced network of simultaneously operating geophysical sensors. Each station would weight about 100 lbs. not including the descent vehicle. Besides scientific instruments, an RGM includes a power supply, transmitter and reciever, command decoder, and a data subsystem. The lifetime of the RGM will vary from 2 to 5 years. The RGM will be powered by the System for Nuclear Auxiliary Power (SNAP) 19 RTG. Objectives of the RGM are (1) to provide a widely spaced net of seisometers, gravimeters, and transponders, (2) to serve as outlying stations in conjunction with an ESS and EXESS central station, and (3) to be deployed along LSSM unmanned traverses at approximately 50 km intervals.

RGM candidate experiments include:

- active/passive seismic
- gravimeter (geodetic)
- doppler transponder
- total pressure gage
- mass spectrometer

3.2 Lunar Experiment Equipment

The experiments and equipment associated with Stage I and II missions are summarized in Table 5.

3.2.1 Stage I Equipment

The Apollo Lunar hand tool package, to be available for the geology work will include, in a tool carrier, the following items:

hammer
scoop
sample bags and small containers
drive tubes
aseptic samplers
tongs
hand lens/scriber/brush tool

A Lunar Survey System Staff (LSSS) is being developed to support surface activities. This device will aid in monitoring the position of an astronaut in the field and will carry, in the early version, the following units: camera & film; and a penetrometer.

The camera to be employed during these missions will be hand held and will record terrain information during exploratory

TABLE 5.

MISSION EXPERIMENT & EQUIPMENT

EXPERIMENT/ ACTIVITY	EQUIPMENT: Stage I — Early Apollo	Stage I — Apollo	Stage II — AAP
Tracking/ranging	Manual Azimuth Range finder Apollo TV	Manual azimuth Range finder Apollo TV	Automatically on LM LSSM TV
Navigation	Manual	Manual	LFU, LSSM
Cameras	Hasselblad	Stereo	Stereo
Sampling	Apollo Lunar hand tools (ALHT) 3 m drill	ALHT 3 m drill	Improved ALHT 100 m drill
Data Collection	EASEP	ALSEP	ESS, EXESS, RGM
Seismic Experiment	Passive	Passive or Active	Active

traverses. Design requirements for this camera are as follows:

- use of interchangable film
- capability of color or black and white photographs
- capability of stereo or simple exposures
- provide capacity to identify objects 0.1 mm in linear dimension
- capability to photograph in UV and IR spectral ranges
- weight and volume - 7lbs, .25 ft.^{3}
- film capacity - 300 stereo pairs
- record of real-time of exposure

A portable, hand held three meter drill will be available for a variety of reasons. The ability to drill and take cores is not only an objective of geological investigation, but will provide data to other disciplines by performing experiments on the electrical properties of the area, radioactivity, fields, heat flow, and active seismic characteristics.

A flying vehicle may be available on these missions, but only as an emergency device to permit the crew to return to the orbiting command and service module in the event the LM cannot ascend.

3.2.2 Stage II Equipment

During the Stage II lunar operation, man's capability to remain on the moon will be extended. The lunar stay time will range from seven days up to six months. In order to maximize the scientific return and increase cost effectiveness during this time period, man must be provided with a mechanical means of locomotion. This will allow him to extend his range of lunar exploration, deploy more scientific equipment over greater area, and provide a higher yield of lunar samples. The lunar locomotion concepts that have been proposed divide themselves into two categories:

- Lunar surface vehicles
- Vehicles that operate above the lunar surface

The latter class of vehicle is referred to, somewhat inaccurately, as a lunar flyer. For purposes of simplicity, this report shall also call them flyers.

The vehicle that will transport crew and equipment to the moon for the Stage II lunar exploration will be based on the Saturn-Apollo system. This system utilized the lunar orbit rendezvous (LOR) flight mode. The command service module (CSM) acts as a shuttle craft, ferrying the three-man crew to lunar orbit, and remains in lunar orbit while two of the crew descends to the lunar surface in the Lunar Module (LM). Upon completion of the lunar stay, the crew is inserted into lunar orbit by the LM ascent stage, leaving the burnt-out descent stage on the moon. The LM ascent stage then performs rendezvous and docking with the CSM. The LM crew transfers to the CSM, and the LM is jettisoned. The remainder of the mission is accomplished in the CSM.

Stage II lunar exploration will require two Saturn-Apollo vehicles per mission, one for cargo and one for the lunar exploration team. The cargo carrier will differ from the present

Saturn-Apollo in that it will not contain provisions for a crew to land on the moon. The CSM will be in the present configuration, as the crew will fly the cargo to lunar orbit and then return to earth. The ascent stage of the LM will be deleted and replaced by cargo. The cargo typically will be some form of lunar locomotion mounted on the LM descent stage. The LM descent stage will be modified to provide for guidance, navigation, and attitude control. This resultant LM configuration is referred to as a LM/Truck. A Saturn-Apollo configured as such can deliver approximately 8000 lb. (3600 KG) to the lunar surface.

A representative flight plan utilizing the LM truck would be as follows:

1. The cargo carrier, consisting of a CSM and three-man crew, plus the LM/Truck and cargo is launched. This vehicle executes the nominal Apollo flight path into lunar transit.

2. The CSM and LM/Truck enter lunar orbit.

3. The unmanned LM/Truck is separated from the CSM.

4. LM/Truck executes descent orbit insertion, and follows nominal lunar landing trajectory under automatic guidance.

5. The CSM returns to earth, following the nominal Apollo flight path.

The personnel carrier, although identical to the present Saturn-Apollo configuration, including the CSM and LM, is designated the LM/Taxi. Normal operating conditions indicate a three-week interval between landing the LM/Truck and LM/Taxi on the lunar surface. A contingency analysis indicates that a cargo waiting capability of up to six months is desirable and still cost-effective.

The LOR flight mode, using Saturn-Apollo equipment modified to the LM/Truck-LM/Taxi configuration, can land two lunar explorers with the following equipment:

1. One lunar surface vehicle (LSSM)
2. One lunar flying vehicle (LFU)
3. 750 lb. (350 Kg) of scientific equipment

The maximum lunar stay time is 14 days. During that time, one lunar traverse of 250 miles (400 km) is possible.

An alternate to the LOR flight mode is the so-called direct flight mode. As it implies, there is no rendezvous and docking of spacecraft, and does not contain a vehicle whose sole function is to descend to, and ascend from, the lunar surface. The entire LM is replaced by a liquid hydrogen (LH_2), liquid oxygen (LO_2) propulsion stage. This stage is fitted under the CSM, and is called the Multi-Mission-Module (MMM). It is so designated because this stage has multiple uses in a number of other missions and can be used on other boosters in addition to the Saturn V.

The Direct Flight mode allows the entire CSM, with its three-man crew, to be landed on the lunar surface. The MMM provides thrust for braking and landing. Lunar liftoff is accomplished with CSM propulsion, leaving the burnt-out MMM on the moon. The CSM, after lunar liftoff, inserts into the trans-earth coast, and re-enters earth atmosphere following standard Apollo techniques.

This mode can deliver approximately 30,000 lb. (1400 kg) per landing to the lunar surface. The lunar expedition force consists of three men. The maximum lunar stay time is ninety days. The lunar surface vehicle would provide at least three traverses of 250 mi. (400 km) length. The explorers would be equipped with 3000 lb. (135 kg) of scientific equipment.

The foregoing methods of transporting men and equipment to the lunar surface clearly impose constraints upon the design of lunar surface vehicles. Among these constraints are weight, size, cabin volume, scientific payload, etc. Other constraints and the resolution of design problems, have been derived from analysis of the lunar module. Becker, et al., investigated the theoretical performance of a variety of vehicle types in four different lunar soil models. The only clear-out conclusions drawn from this study are:

1. Rigid wheels are unsatisfactory in soft soil.
2. Wheel diameters should be as large as practical.
3. Ground clearance and angles of approach and departure should be large.
4. The soft ground mobility of tracked and wheeled vehicles is comparable in noncohesive soils.

The question now arises, is a tracked or a wheeled vehicle more suitable to the lunar environs? The answer is found in the mechanical characteristics of the lunar soil. Tracked vehicles show a pronounced superiority over wheels in the traverse of soft, cohesive substances such as mud and snow. Substances which are soft and granular, but have low cohesion, allow wheeled vehicles to perform as well as tracked ones. The Engineering Lunar Model Surface (ELMS) used in the study by von Tiesunhousen, et al, assumes no cohesiveness at all. Present data indicate that there is no reason to expect cohesive-type soil on the moon. In return for a slight advantage, a tracked vehicle would pay the penalties of increased weight, lower reliability and efficiency. The operator of a tracked vehicle pays a penalty also, as the driving forces required for normal (wheel) driving are less.

As stated earlier, the wheel diameter should be as large as practical. This is a function of the LM/Truck geometry. The number of wheels, is in turn, a function of the diameter. This is due to the constant size of the LM/Truck envelope; as the number of wheels becomes great, the diameter must decrease. An additional constraint on the number of wheels is the necessity of avoiding cumbersome stowage techniques. The maximum diameter wheel on a six-wheel vehicle is 60 in. (1.5 meters) and on a four-wheel vehicle, 80 in. (2.0 meters). An eight-wheeled vehicle results in wheel diameters that cause an appreciable net loss of performance. Thus it is seen that the most fruitful concepts for wheeled vehicle is either 4 x 4 or 6 x 6 configuration.

A. Lunar Roving Vehicles

VEHICLE DESIGN DESCRIPTION

In a report on the state of the art of Lunar Roving Vehicles, Aviation Week and Space Technology, January 6, 1969, cites the roving vehicle mission requirements presented in Table 6.

TABLE 6.

ROVING VEHICLE MISSION REQUIREMENTS

Manned Vehicle

Operation by one astronaut but capability to carry with continuous communications and data link to earth.

A navigation system.

A payload of at least 661.3 lbs. in scientific instrumentation and an operational radius of 6.2 mi.

Traverse range per individual sortie of 18.6 mi., speed for flat surfaces of 6.2 mph.

Storage capacity for scientific experiments.

Remote operational capability from earth before, during and after the manned portion of the mission.

Unmanned Vehicles

Scientific payload of 198.4 lb.

Extended mobility of 621.3 mi.

Lifetime of six (6) to twelve (12) months.

Capability of gathering, analyzing, and transporting samples.

Capability of deploying instruments.

Capability of remote operation from earth.

Capability for being launched directly from earth.

Lunar rover vehicles may be conveniently grouped into such categories as remotely controlled vehicle, unmanned-cargo carrier, open-cockpit vehicle, closed-cabin vehicle, & special purpose vehicle.

Stereotypes of each category will be discussed indicating variations in crew size, range, payload, and mission duration within each category.

1. Remotely Controlled Exploration Vehicle

Vehicles of this category have been designated as Remote Unmanned Traverser (RUNT). It is a device designed to be landed on the moon by unmanned vehicle. Its purpose is to travel along the lunar surface while under steering control from earth. The RUNT is equipped with a stereo television camera and illumination source, which provides the earth controllers with a picture of its environment. These data allow the earth controller to drive the vehicle.

An obvious problem with this method of navigation is the time delay in steering commands caused by the earth-moon distance. Transmission time of the TV picture to earth and the appropriate radia steering command is approximately 2.56 seconds (lunar distance of 240,000 miles). This does not take into account the operator reaction time. Reaction time in this case is meant to include perception of the circumstances, evaluation of it, selecting the proper response, and initiating the command.

The range of the RUNT is 200 km and mission duration is 90 days. It has a payload of 50 kg. The RUNT is a four-wheeled vehicle, and tows an antenna mounted on a two-wheeled trailer.

2. Unmanned-Cargo Carrier

This vehicle has been designated as the Pack Mule. The explorer walks alongside this device, which is intended to increase his capacity to deploy scientific equipment and collect lunar samples. Control of the vehicle is exercised by the explorer through a hand-held controller. This is attached to the vehicle by an umbilical. The 4 x 4 Pack Mule has a range of 15 km and carries a 75 kg payload.

A motorized cart is also being developed for single man operation. The astronaut either rides or walks behind the cart, which has a range of 30 miles at a speed of 6 km/hr.

3. Open-Cockpit Vehicle

Two different types of open cockpit vehicle have been proposed, both of which are of the 4 x 4 configuration. One design proposed for transporting an explorer and a minimum of scientific equipment has been designated the Go-Cart. Its function is to rapidly transport the explorer to and from various locations. The Go Cart has been proposed in two variations. One has a range of 240 km and a payload of 10 kg. The other has a range of 144 km and a payload of 75 kg, plus a spare PLSS. The spare PLSS allows the explorer to spend more time at scientific activities away from the LM shelter.

The second type of open vehicle is also designed to transport one man and has been designated the Local Scientific Survey Module (LSSM). The LSSM which carries a wide variety of scientific equipment enabling the explorer to perform many experiments, has been proposed in two versions. Each version has a range of 360 km, mission duration of 14 days, and payload of 320 kg. The baseline LSSM has as its main scientific package a theodolite and ranging laser, and a ground truth package. In addition to these instruments, the greater versatility LSSM has stereo TV, a 655 watt RTG, radiator and auxiliary radiator, and astrionics package.

4. Closed-Cabin Vehicle

These vehicles are typified by combining in a single system the requirements necessary to provide the explorers with a shirt-sleeve environment for an extended stay time, provisions for utilizing scientific equipment and data transmission, and the means of conducting an extended traverse. The purpose of closed cabin vehicles is essentially to provide a mobile laboratory that makes the explorers independent of their base site. One general class of closed vehicle has been designated as the Molab which have been designed for two-and three-man crews. The two-man Molab vehicles have a range of approximately 400 km, mission duration of 14 days and a payload of 320 kg. The three-man Molab has been designed with the same capabilities as the two-man Molab.

Another class of three-man closed-cabin vehicle has been designated as the Mobex. Three configurations have been proposed. Ranges of these vehicles are 800 km, 1600 km, and 3425 km. Corresponding mission durations for the configurations are 28 days, 42 days, and 90 days respectively. The payload for the 28 day mission is 700 kg, while the payload for the 45 and 90 day mission is 1500 kg.

The Molab and Mobex vehicles discussed above are 4 x 4 configuration. A 6 x 6 semi-articulated configuration has been proposed by Mitcham et al. The four-wheeled cabin unit houses the crew, while a two-wheeled unit containing the power system is towed behind. It is a two-man vehicle and can be delivered to the lunar surface by a LM/Truck. The 6 x 6 offers increased reliability over the 4 x 4 configuration, as all six wheels are powered and braked.

5. Special-Purpose Vehicles

While it may be said that all of the preceeding vehicles are indeed special purpose, each of them can be used in a variety of ways. This section describes vehicles designed for a single unique function.

One function is to transport large quantities of lunar samples or scientific equipment. To this end, trailers have been designed to be towed by the LSSM, Molab, and Mobex. The respective payload of each trailer is 987 kg, 2798 kg, and 6441 kg. They are all of the 4 x 4 configuration.

A lunar tractor has been designed, incorporating a .37 m^3 backhoe with outriggers, a 3.65 m bulldozer blade, and a soil/cargo hopper. This vehicle is of 8 x 8 configuration and is capable of 15 km/sortie. The payload is 1809 kg. The one-man crew utilizes his PLSS while operating the tractor.

A two-man 4 x 4 Molab has been modified to include a .37 m^3 backhoe with outriggers. This vehicle is capable of 400 km/sortie. The payload is reduced from 320 kg in the normal two-man Molab to 290 kg.

A summary of performance data for the various roving vehicle configurations described above is presented in Table 7.

TABLE 7.

SUMMARY OF LUNAR ROVING VEHICLE PERFORMANCE DATA

VEHICLE	MEN	PAYLOAD (Kg)	RANGE (Km)	SPEED (km/hr)	DURATION (Days)
RUNT	Unmanned	50	200	-	90
Pack Mule	Unmanned man controlled	75	15	-	
Motorized cart	One man	347	48	6	
Open cock-pit					
Go cart 1	One man	10	240		
Go cart 2	One man	75	144		
LSSM	One or two	320	360		14
Bendix base-line LRV	One or two	367	30	8.6	
Closed cabin					
Molab	Two or three	320	400		14
Mobex 1	Three men	700	800		28
Mobex 2	Three men	1500	1600		42
Mobex 3	Three men	1500	3425		90
Special Purpose Vehicles					
LSSM trailer	Unmanned	987			
Molab trailer	Unmanned	2798			
Mobex trailer	Unmanned	6441			
Lunar tractor	One man	1809	15		
Modified Molab	Two men	290	400		

Sample Mission Using Lunar Roving Vehicles

Some three weeks after the unmanned LM/Truck has delivered the Molab to the lunar surface, the manned LM/Taxi lands approximately one mile (1.6 Km) from it. The Molab located at the LM/Truck landing site, is then activated and driven to the LM/Taxi by remote control. In the event that the remotely controlled unloading of the Molab, attempted at the time of initial landing, was unsuccessful, the explorers will walk to the LM/Truck and attempt to unload the Molab manually. Assuming all remote control functions were successfully achieved, the Molab would arrive at the site of the Lm/Taxi while unmanned. The explorers then shut down the LM/Taxi, and it would remain dormant for the remainder of the lunar exploration. The explorers next perform a comprehensive systems checkout of the Molab. Driving performance is checked by following the Molab tracks back to the LM/Truck. This insures a viable pathway, and allows the crew to concentrate on vehicle familiarization and perfecting lunar driving techniques. In this manner, engineering and operational test objectives are satisfied.

Upon arrival at the LM/Truck, scientific instruments will be unloaded from the truck, deployed, activated, and readied for continuous, automatic transmission of data back to earth. The LM/Truck is now an emplaced scientific station. It will remain active for about one year. In the process of converting the LM/Truck to a scientific station, the explorers will accomplish a geological reconnaissance of the site. Thus, the LM/

Truck constitutes station I of the lunar traverse. It is estimated that the scientific and explorative activities at this station will require approximately two days. The pre-planned traverse will then be resumed, going on to subsequent stations. Each station has scheduled activities associated with it. The stations will be arranged such that the path the Molab follows is generally circular, ending back at the site of the Lm/Truck. This completes the first loop of the traverse. The Molab path in a nominal mission would describe a double loop, or figure eight.

Driving time between stations is estimated to be several hours. Routine functions, such as housekeeping, sleeping, communications with earth, are scheduled throughout the traverse. These functions are nominally associated with the interval spent at a station. Unscheduled time is provided during the traverse in order to allow man to exercise his greatest talent: improvization. As unforeseen and scientifically interesting lunar features are encountered, the explorers will deviate from the pre-scheduled traverse in order to pursue what seems to be the most fruitful course. This requires exercising keen judgment by both the lunar explorers, and by mission controllers on earth. It is only by allowing real time changes, as warranted by existing circumstances, that the full potential of manned, rather than automated, lunar exploration can be realized.

The first loop of the traverse is conducted in sunlight.

When this loop is completed and the Molab arrives back at the LM/Truck, a system check is initiated. The result of this check provides the basis for embarking on the second loop of the traverse. The second loop is accomplished in the lunar night, and the method is essentially the same as that in the first loop. That is, there are pre-planned stations to be visited, scientific equipment to be deployed, and specific activities to be accomplished. The terminus of the night loop is at the LM/Taxi site, and in effect, marks the completion of the lunar mission. The lunar explorers board the LM/Taxi, initiate lunar liftoff, and follow nominal Apollo rendezvous and docking techniques to rejoin the orbiting CSM.

This mission plan provides for a Lunar Flying Vehicle (LFV) to be landed by the LM/Truck along with the Molab. The LFV is mounted on the Molab, and is transported by it through the double loop traverse. The LFV thus serves as an emergency back-up mode of transportation for the crew. The LFV would not be used in the course of a nominal, successful traverse. However, at the completion of the double loop, the explorers have the option of venturing into new territory via the LFV. The sortie would be of most value when directed towards areas not accessible via surface locomotion, e.g., mountain peaks, crater interiors, etc.

B. Lunar Flying Vehicles

Lunar Flying Vehicles (LFV), or as they are sometimes known, Manned Flying System (MFS), offer several advantages over surface forms of locomotion. Sorites in other-than Molab type vehicles are limited by the capability of the explorer's Portable Life Support System (PLSS). The back mounted PLSS allows the astronaut to venture into the lunar environment for only three hours. In order to maximumize useful work during this time, travel time to and from work sites must be kept as short as possible. The MFS provides flight at speeds such that the travel time is negligible. This allows the explorer to devote almost all of the three hours to scientific endeavors. The speed, range, and payload capacity of lunar flyers make them highly suitable as a means of accomplishing scientific tasks in the lunar environment. The speed and altitude of the MFS is a function of range to go and thrust to weight. Maximum speed approaching 500 fps, and altitudes in excess of 6,000 ft. are possible. In addition, as the flight time is short, the operator is not subjected to driving stress for extended periods of time. Another advantage is that the MFS is not affected by lunar surface unknowns.

Manned Flying System Design

Concepts for three types of manned flying systems have been developed. These are:

1. Lunar flying unit, sometimes called POGO
2. Lunar flying vehicle, for exploration or rescue
3. Return to orbit

Each concept has been developed with a variety of capabilities. The POGO comes in various sizes. These are similar, but the range of the device varies. Proposed concepts provide for ranges of 8, 20, and 170 km.

Exploration or rescue lunar flying vehicles have been designed for one, two, and three-man capabilities. One and two-man vehicles are essentially the same, as the payload in a one-man vehicle replaces the second astronaut. Ranges for these LFV's have been proposed as 20, 50, 100, and 200 km. The ranges of the three-man type has been proposed as 50, 200, 400, and 800 km.

The range of the Return to Orbit vehicle is self-explanatory. These have been proposed sized for both two and three men.

A design for a LFV was recommended by Levin and Nelson, of Bell Aerospace. The design calls for an open cockpit vehicle that can carry two pressure-suited astronauts. Major goals and design philosophy are recommended to be:

1) Compatibility of the LFV with the LM/Truck and Molab in terms of minimum mass and volume.

2) Maximum system simplicity in concept and operation, and optimum use of the astronaut in the guidance, navigation and flight control task.

3) Long-time storage (up to 180 days) in the lunar environment in addition to the 14-day Molab operations period.

4) Capability for flight by either a modified ballistic or hover translation flight path at the discretion of the astronaut.

5) Provisions for complete operation by one man (assuming a crew of one or two men) and switch over of control from one crew member to the other in flight.

The typical LFV, as proposed by Bell Aerosystems, has the capability to provide round trip transportation of an astronaut and up to 136 kg (300 lbs) of payload to sites up to 25 km (15mi) away from the LM-Shelter. This vehicle may be configured so that a second astronaut may be carried in lieu of the payload. Environmental control for the astronaut is provided by his backpack PLSS. The astronaut and payload occupy positions on a platform which is located to balance the vehicle. The platform is adjustable to compensate for varying loads. The astronaut must estimate the amount of consumables used up, and the weight of the payload. He then adjusts the platform accordingly, locks it in place, thus making the LFV ready for flight.

The landing gear consists of four leg assemblies and foot pads. Each leg assembly has three members equipped with a re-usable friction type energy absorption system.

The major components of the propulsion system are the lift thruster assembly, attitude thruster assemblies, propellant tanks, and pressurant tanks. Lift is provided by five throtteable rocket engines, installed as a unit in the center of the vehicle. The altitude control system is comprised of six rockets. Propellants for this system are supplied from the main tanks, installed in the outer compartments. Studies by Bell indicate they should be sized according to the particular mission the vehicle is to fly. The mass saved by these means can then be assigned to the Shelter Payload which includes the mobility system (MFS and propellants), the scientific equipment and the PLSS expendables.

If 14-day tanks are used and off-loaded for a 3 day mission, the shelter payload is 3875 lbs. Similarily, for a 6 day mission, the shelter payload is 3625 lbs. If the tanks are made only large enough to contain the required amounts, the shelter payload for a 3 day mission is increased to 4620 lbs., and for a 6 day mission, to 4145 lbs.

The navigation, guidance, and flight control is provided by a strapdown type guidance system utilizing three rate integrating gyros and two accelerometers and associated electronics and computer. A radar altimeter is also used for altitude information. The system provides the astronaut with rate command and attitude hold type vehicle control which results in the vehicle holding the attitude resulting from the last command. A display and control system provides the astronaut with the information required and the hand controllers necessary to monitor altitude and fly to the desired destination. The attitude controller is mounted on the right hand side of the console and the lift throttle to the left hand side of the platform. This position and function is similar to that of the lift control on a helicopter.

A mockup evaluation conducted by Bell demonstrated that the console should be offset to the right in order not to occupy too large a portion of the astronaut's visual field. It was further demonstrated that this could be done, thus providing good forward and downward vision, while retaining displays within the recommended foreward visual cone. Controls for right handed operation were also within comfortable reach when located on the off set console. The Bell study concluded that the left hand face of the console be placed approximately five inches to the right of the centerline of the operators seat. This resulted in the best combination of forward vision and view of the displays.

A representative payload equipment list for the LFV is as follows:

10 ft. drill

meteoroid ejecta detector

Tissue Equivalent Ion Chamber

Surveying Staff

Sample containers and hand tools

Theodolite and Ranging laser

Surveying Markers

Gravimeter

Magnetometer

Gas analyzer

Penetrometer

Surface Electrical Package

Radiometer

Sketchboard and Maps

4 - 70 mm Framing Cameras

TV

Platforms and Mounting for Cameras and TV

Sonic Velocity Logging

Side Looking Radar

RF Reflectivity

Gamma Ray Spectrometer

In addition, the vehicle will be equipped with VHF communications and S-Band communications, including omnidirectional and high gain antennas.

A second class of lunar flyer is called the Lunar Flying Unit (LFU). It is a smaller device than the LFV, and is capable of transporting one man. Due to the geometry of this device, it is sometimes called the "Pogo Stick". The operator places his feet on the lower cross bar, and grasps the control handles with his hands. Two rocket nozzles are gimbal mounted and controlled directly by the operators hand, arm, and shoulder motions. The system requires no electronics or stability augmentation. The right hand twist grip controls thrust. The left hand twist grip controls yaw of the vehicle through the use of the jetavator rings. Pitch control is produced by moving the handles up and down. Roll control is produced by tilting the handles clockwise or counterclockwise. ECS is provided by the astronauts PLSS.

The LFU uses visual/manual guidance techniques. A timer is provided to assist in trajectory control and guidance to the destination.

The LFU can provide one man transportation over a 21 km round trip sortie. During this sortie, it can carry a maximum payload of 200 pounds. There is no provision for carrying a second astronaut in lieu of payload.

Sample Mission Using Lunar Vehicle

Two different types of missions have been studied by Bell Aerosystems to determine the scientific activities which are made possible by the unique capabilities of a Lunar Flying Vehicle. (Bell report no. 7243-950002, Vol. II).

The first mission has as its goal the installation of four Emplaced Scientific Stations (ESS). The ESS's will be at the center and apexes of an equilateral triangle laid our over a large area of the lunar surface. Factors which determine the size of the triangle are: mission duration, LM shelter payload, and scientific equipment to be deployed. A three day mission can accomplish deployment of the four ESS's at a radius of 36.2 km (20 mi.). A round trip is made from the LM shelter to each location when a station is emplaced, and another payload for the outward trip is picked up. The payload includes cameras for in-flight use, and instruments to be used at the site. At the site, the astronaut logs data and collects samples. He also explores the immediate region. In the three day mission plan, only 15 hours are allowed for accomplishing the scientific efforts. The remainder of the time is used up by engineering, housekeeping, communications, and personal activities.

On a 14 day mission, the ESS's are deployed 14.5 km (9 mi.) from the center base. This mission uses the same scientific equipment as the 3 day mission. The decrease in deployment range is due to the decreased shelter payload. The Shelter payload provides enough PLSS expendables for about 9 hours/day of activity outside the shelter. This allows for intensive local geographical and topographical exploration.

It can be seen that as the mission time varies from 3 to 14 days the amount of scientific time spent in particular areas varies. Short missions (3-4 days) result in wide spread deployment of ESS's, with little or no time for other scientific activities. Longer, near maximum missions (about 14 days) allow for longer scientific time spent in the primary or base site, but less widely dispersed ESS's.

The second type of mission is essentially explorative in nature. Missions of 3 and 6 days were examined. A 6 day mission would allow six exploration sorties, flown to 10 different locations. A seismic refraction experiment is performed with 6 charges placed at 1.6 Km (1 mi.) intervals. On-site time varies from 1.5 hours to 3 hours. Six hour sorties are possible by having the explorers take along an extra PLSS, and changing PLSS's when the first one is expended. While flying to the sites, surveys are made via instruments for in-flight sensing. Additional in-flight experiments include magnetic fields measurements, multi-band photography, and gamma-ray spectroscopy. The 10 sites are explored with 8 instruments, in-flight measurements are made with 5 instruments. The sites are within a circle of 627 sq km (241 sq. mi.) area. The objective is to explore each different feature in the area with many different kinds of instruments.

On the three day mission, the objective is to examine all the different features with as broad coverage as possible and to complete the mission in the specified time. Twenty sites are visited and 7 instruments are used in the ½ hour spent at each site. The same in-flight sensors are used as in the 6 day mission. The general area covered is a circle 855 sq km (330 sq. mi.).

Sample LFU Mission

The LFU could be used to augment a LM mission. The augmented LM (ALM) which provides taxi, shelter, and logistics functions, is placed on the lunar surface for a stay time of up to 3½ days. Typically, the LFU would be used to rapidly deploy scientific equipment. It is a useful tool in reducing the work load imposed on the astronaut/explorer. It also maximizes work time at stations, as it reduces travel time. The use of an LFU permits the accomplishment of some experiments and activities in a six day mission which would require an LSSM 14 days to accomplish. Use of the LFU insures that the scientific equipment would be deployed at all pre-planned sites, as virtually no location is inaccessible.

3.3 Astronaut Operations

Since many of the details of lunar missions have not yet been specified it is difficult to present an actual astronaut time line for proposed missions. Operational requirements for early Apollo are available, however the activities and operational sequences for AAP and even Apollo missions must be framed in terms of a representative listing.

3.3.1 Stage I Missions

The sequences of operations associated with deployment and activation of two EASEP experiments are presented in tables 8 and 9. Table 8 contains the operational sequence and time line for deployment of the Passive Seismic Experiment (PSE). Table 9 presents procedures for deploying the Laser Ranging Retro-Reflector (LRR). As indicated in these tables, the time allocated for setup of the PSE is 15 minutes while the time available for LRR deployment is 11 minutes.

As specified by the 1965 Summer Conference on Lunar Exploration at Falmouth, Massachusetts, the highest priority of work time on early lunar surface missions should be given to sample collections. Samples should be collected from as far from the LM and from as many sites as is possible. A sufficient sample would be from .25 to .5 kg for each site.

In a study of astronaut activities in early lunar flights, Edmonds (1966) noted that for a geologic mission the activities and percentages of total time were: geologic description, 33 percent; photography, 8 percent; sampling 19 percent; and walking, 22 percent. These activities add up to 82 percent with the remaining 18 percent spent in miscellaneous activities.

Results of his studies led Edmonds to conclude that even on traverses as short as those planned for early Apollo, a significant amount of data on the geology of an area can be processed when it is gathered, transmitted, and analyzed by a team of professional geologists (Edmonds, 1966).

TABLE 8.

EASEP PROCEDURES FOR THE PASSIVE SEISMIC EXPERIMENT

TASK NO.	TASK DESCRIPTION	TASK TIME	CUMULATIVE TIME
1.0	REMOVE EASEP PACKAGE NO. 1 (Total Time=3:35)		
1.1	Retrieve Scientific Equipment Bay (SEQ) by Door deployment lanyard	00:10	00:10
1.2	Walk 5 feet from LM, deploying lanyard	00:05	00:15
1.3	Pull SEQ Bay Door deployment lanyard to open SEQ Bay Door	00:15	00:30
1.4	Return to SEQ Bay Compartment II.	00:15	00:35
1.5	Restow SEQ Bay Door deployment lanyard	00:10	00:45
1.6	Walk to SEQ Bay Compartment I	00:03	00:48
1.7	Retrieve EASEP Package No. 1 deployment lanyard	00:10	00:58
1.8	Walk 10 feet from LM, deploying lanyard	00:10	01:08
1.9	Pull EASEP Package No. 1 deployment lanyard to release Package No. 1 tie-downs, extend boom assembly to lower Package No. 1 to the lunar surface	00:25	01:33
1.10	Discard EASEP Package No. 1 deployment lanyard	00:02	01:35
1.11	Walk to Package No. 1	00:05	01:40
1.12	Use two hands to pull in opposite directions to release deployment lanyard from EASEP Package No. 1	00:10	01:50
1.13	Walk to rear of EASEP Package No. 1	00:05	01:55
1.14	Remove boom assembly pull pin to release deployment handle and to separate EASEP Package No. 1 boom attachment assembly	00:07	02:02
1.15	Walk to front of EASEP Package No. 1	00:05	02:07
1.16	Retrieve EASEP Package No. 1 deployment lanyard	00:05	02:12
1.17	Walk 5 feet back from EASEP Package No. 1, deploying lanyard	00:05	02:17
1.18	Pull EASEP Package No. 1 deployment lanyard to restow boom assembly	00:20	02:37
1.19	Walk to SEQ Bay Compartment I	00:10	02:47
1.20	Restow EASEP Package No. 1 deployment lanyard	00:10	02:57

Table 8 (continued)

1.21	Walk to SEQ Bay Compartment II	00:03	03:00
1.22	Retrieve SEQ Bay Door deployment lanyard.	00:10	03:10
1.23	Walk 5 feet from LM, deploying lanyard.	00:05	03:15
1.24	Pull SEQ Bay Door deployment lanyard to close SEQ Bay Door.	00:10	03:25
1.25	Discard SEQ Bay Door deployment lanyard.	00:02	03:27
1.26	Walk to EASEP Package No. 1.	00:08	03:35
2.0	TRAVERSE TO DEPLOYMENT SITE (Total Time=3:30)		
2.1	Use carry handle to lift EASEP Package No. 1 from lunar surface	00:05	03:40
2.2	Walk around LM to Descent Stage ladder.	00:35	04:15
2.3	Lower EASEP Package No.1 to lunar surface.	00:05	04:20
2.4	Rest and survey lunar surface to select suitable EASEP Package No. 1 deployment site	02:00	06:20
2.5	Use carry handle to lift EASEP Package No. 1 from lunar surface	00:05	06:25
2.6	Walk 30 feet from LM to select EASEP Package No. 1 deployment site.	00:30	06:55
2.7	Lower EASEP Package No. 1 to lunar surface on E-W axis.	00:10	07:05
3.0	<u>DEPLOY PSEP</u> (Total Time=6:17)		
3.1	Smooth out EASEP Package No 1 deployment site with EMU boot.	01:00	08:05
3.2	Walk to rear of EASEP Package No. 1.	00:05	08:10
3.3	Grasp deployment handle, pull to extend handle to 30 inch working height, and rotate handle 90^0 to lock it in place.	00:10	08:20
3.4	Walk to front of EASEP Package No. 1.	00:05	08:25
3.5	Grasp carry handle with left hand.	00:03	08:28
3.6	Use right hand to remove and discard first solar panel-restraining pull pin.	00:10	08:38
3.7	Remove and discard first solar panel support bracket-restraining pull pin.	00:05	08:43
3.8	Grasp first solar panel support bracket, rotate bracket forward, lift bracket upward to release and remove first rear support bracket pull pin, and discard bracket/lanyard/pull pin.	00:20	09:03

Table 8 (continued)

3.9	Grasp carry handle with right hand.	00:03	09:06
3.10	Use left hand to remove and discard second solar panel-restraining pull pin.	00:10	09:16
3.11	Remove and discard second solar panel support bracket-restraining pull pin.	00:05	09:21
3.12	Grasp second solar panel support bracket, rotate bracket forward, lift bracket upward to release and remove second rear support bracket pull pin, and discard bracket/lanyard/pull pin	00:20	09:41
3.13	Use carry handle to rotate EASEP Package No. 1 to the lunar surface.	00:10	09:51
3.14	Use deployment handle to embed EASEP Package No. 1 mounting tabs in lunar surface.	00:20	10:11
3.15	Release velcroed antenna release lanyard from deployment handle.	00:05	10:16
3.16	Pull antenna release lanyard to remove antenna pull pin, release and rotate PASSIVE SEISMIC EXPERIMENT gnomon, and release and rotate antenna. (Steady EASEP Package No. 1 by holding with left hand.)	00:10	10:26
3.17	Discard antenna release lanyard.	00:02	10:28
3.18	Release first velcroed solar panel deployment lanyard from deployment handle.	00:05	10:33
3.19	Pull first solar panel deployment lanyard to rotate first set of solar panels. (Steady EASEP Package No. 1 by holding deployment handle with left hand and monitor solar panel deployment.)	00:20	10:53
3.20	Check for solar panel separation from lunar surface	00:05	10:58
3.21	Discard first solar panel deployment lanyard.	00:02	11:00
3.22	Release second velcroed solar panel deployment lanyard from deployment handle.	00:05	11:05

Table 8 (continued)

3,23	Pull second solar panel deployment lanyard to rotate second set of solar panels. (Steady EASEP Package No. 1 by holding deployment handle with left hand and monitor solar panel deployment.)	00:20	11:25
3.24	Check for solar panel separation from lunar surface.	00:05	11:30
3.25	Discard second solar panel deployment lanyard.	00:02	11:32
3.26	Request antenna elevation offset from MCC.	00:10(*)	11:42
3.27	Receive antenna elevation setting from MCC.	00:10(*)	11:52
3.28	Grasp antenna, rotate antenna to designated elevation offset, and release antenna.	00:15	12:07
3.29	Observing PSE bubble level, use deployment handle to level EASEP Package No. 1 to within +5° of lunar vertical.	00:10	12:17
3.30	Observing shadow cast by PSE gnomon on partial compass rose, use deployment handle to align EASEP Package No. 1 to within $\pm 5^{\circ}$ of PSEP certerline and release deployment handle.	00:20	12:37
3.31	Observe PSE bubble level to ascertain if EASEP Package No. 1 is still within $\pm 5^{\circ}$ of lunar vertical. (Relevel and realign, if necessary.)	00:05	12:42
3.32	Observe PSE bubble level and report degree of PSEP leveling to MCC.	00:10(*)	12:52
3.33	Recieve acknowledgement from MCC.	00:10(*)	13:02
3.34	Observe PSE sun compass and report degree of PSEP alignment to MCC.	00:10(*)	13:12
3.35	Receive acknowledgement from MCC.	00:10(*)	13:22
4.0	DEPLOY SOLAR WIND (Total time - 1:26)		
4.1	Unstow tethered Universal Handling Tool	00:02	13:24
4.2	Use UHT to release four Boyd bolts on SWS	00:32	13:56
4.3	Engage UHT in SWS carry socket	00:05	14:01

Table 8 (continued)

4.4	Use UHT to remove SWS from sunshield and to carry SWS 13 feet south of Central Station	00:11	14:12
4.5	Extend four leveling legs to locked position	00:08	14:20
4.6	Emplace SWS on lunar surface and align by observing shadow cast on sensor head	00:10	14:30
4.7	Disengage UHT from SWS	00:05	14:35
4.8	Use UHT to check for freedom of movement around SWS E-W axis	00:04	14:39
4.9	Return to Central Station	00:09	14:48
5.0	TRAVERSE TO LM (Total Time = 0:30)		
5.1	Return to LM	00:30	15:18

(*) Task time includes six second transmission time for translunar voice link.

TABLE 9.

EASEP PROCEDURES FOR LASER RANGING RETRO-REFLECTOR

TASK NO.	TASK DESCRIPTION	TASK TIME	CUMULATIVE TIME
1.0	REMOVE EASEP PACKAGE NO. 2 (Total time = 3:14)		
1.1	Retrieve SEQ Bay door deployment lanyard	00:10	00:10
1.2	Walk 5 feet from LM, deploying lanyard	00:05	00:15
1.3	Pull SEQ Bay Door deployment lanyard to open SEQ bay door	00:15	00:30
1.4	Return to SEQ bay compartment II	00:05	00:35
1.5	Restow SEQ bay door deployment	00:10	00:45
1.6	Retrieve EASEP Package No. 2 deployment lanyard	00:10	00:55
1.7	Walk 10 feet from LM, deploying lanyard	00:10	01:05
1.8	Pull EASEP Package No. 2 deployment lanyard to release Package No. 2 tie-downs, extend boom assembly, and to lower Package No. 2 to the lunar surface.	00:25	01.30
1.9	Discard EASEP Package No. 2 deployment lanyard	00:02	01:32
1.10	Walk to Package No. 2	00:05	01:37
1.11	Use two hands to pull in opposite directions to release deployment lanyard from EASEP Package No. 2	00:10	01:47
1.12	Remove boom assembly pull pin to separate EASEP Package No. 2 from boom attachment assembly and discard pull pin	00:05	01:52
1.13	Retrieve EASEP Package No. 2 deployment lanyard	00:05	01:57
1.14	Walk 5 feet back from EASEP Package No. 2 deploying lanyard	00:05	02:02
1.15	Pull EASEP Package No. 2 deployment lanyard to restow boom assembly	00:20	02:22
1.16	Walk to SEQ bay compartment II	00:10	02:32
1.17	Restow EASEP Package No. 2 deployment lanyard	00:10	02:42
1.18	Retrieve SEQ bay door deployment lanyard	00:10	02:52
1.19	Walk 5 feet from LM, deploying lanyard	00:05	02:57
1.20	Pull SEQ bay door deployment lanyard to close SEQ bay door	00:10	03:07
1.21	Discard SEQ bay door deployment lanyard	00:02	03:09
1.22	Walk to EASEP Package No. 2	00:05	03:14

Table 9 (continued)

2.0	TRAVERSE TO DEPLOYMENT SITE (Total time = 3:30)		
2.1	Use carry handle to lift EASEP Package No. 2 from lunar surface		03:19
2.2	Walk around LM to descent stage ladder	00:35	03:54
2.3	Lower EASEP Package No. 2 lunar surface	00:05	03:59
2.4	Rest and survey lunar surface to select suitable EASEP Package No. 2 deployment site	02:00	05:59
2.5	Use carry handle to lift EASEP Package No. 2 from lunar surface	00:05	06:04
2.6	Walk 30 feet from LM to selected EASEP Package No. 2 deployment site	00:30	06:34
2.7	Lower EASEP Package No. 2 to lunar surface on E-W axis so that LRRR will be directed toward sub-earth point when EASEP Package No. 2 is in the deployed position	00:10	06:44
3.0	DEPLOY LRRR (Total time - 3:55)		
3.1	Smooth out EASEP Package No. 2 deployment site with EMU boot	01:00	07:44
3.2	Grasp deployment handle and associated deployment handle pull pin	00:03	07:47
3.3	Pull deployment handle to extend deployment handle six inches to first detent position and to partially release LRRR array	00:05	07:52
3.4	Discard deployment handle release ring and attach pull pin	00:02	07:54
3.5	Request array tilting offset from MCC	00:10(*)	08:04
3.6	Receive array tilt setting from MCC	00:10(*)	08:14
3.7	Re-grasp deployment handle with left hand to steady EASEP Package No. 2 and, using right hand, grasp array tilting handle, pull outward, rotate handle 45°, and continue pulling array tilting handle outward to extend array tilting handle 9.5 inches to detent position and to complete release of LRRR array	00:15	08:29

(*) = Task time includes six second transmission time for trans-lunar voice link

Table 9 (continued)

3.8	Observing array tilt angle indicator and pointer, use array tilting handle to set in array tilt angle, while using deployment handle to steady EASEP Package No. 2	00:10	08:39
3.9	Partially release outward tension on array tilting handle and check to ensure that array is locked in place	00:05	08:44
3.10	Release array tilting handle and allow array tilting handle to spring back into stowed position	00:03	08:47
3.11	Re-grasp deployment handle, depress trigger on deployment handle to release first detent, pull deployment handle to extend deployment handle an additional 27 inches, and use deployment handle to control descent of EASEP Package No. 2 as it rotates to the lunar surface	00:15	09:02
3.12	Observing EASEP Package No. 2 bubble level, use deployment handle to embed EASEP Package No. 2 mounting tabs in lunar surface and to level EASEP Package No. 2 within $\pm 5^{\circ}$ of lunar vertical	00:30	09:32
3.13	Observing shadow cast by EASEP Package No. 2 gnomon on partial compass rose, use deployment handle to align EASEP Package No. 2 within $\pm 5^{\circ}$ of LRRR centerline and release deployment handle	00:20	09:52
3.14	Observe EASEP Package No. 2 bubble level to ascertain if EASEP Package No. 2 is still within $\pm 5^{\circ}$ of lunar vertical (Relevel and realign, if necessary).	00:05	09:57
3.15	Observe EASEP Package No. 2 bubble level and report degree of LRRR leveling to MCC	00:10(*)	10:07
3.16	Receive acknowledgement from MCC	00:10(*)	10:17
3.17	Observe EASEP Package No. 2 sun compass and report degree of LRRR alignment to MCC	00:10(*)	10:37
3.18	Receive acknowledgement from MCC	00:10(*)	10:37
4.0	TRAVERSE TO LM (Total time - 0:30)		
4.1	Return to LM	00:30	11:07

TABLE 10.

SUMMARY OF PERCEPTUAL/MOTOR REQUIREMENTS FOR EASEP EXPERIMENT DEPLOYMENT

	Experiment	
PSE And Solar Wind (Table 8)		LRRR (Table 9)
Walking		
number of traverses	18	10
distance traveled	168 ft.	115 ft.
Observation tasks	8	9
Lifting tasks	2	2
Resting		
number of rests	1	1
duration of rest	2 min	2 min
Communication with Earth		
number	2	2
Number of manual tasks pulling, retrieving, etc.	45	28

During early Apollo flights the LM Z axis (fore-aft) will be aligned west to east with the front of the LM facing west. This places the sun to the rear of the vehicle at touchdown which facilitates visual surveillance. Upon egressing the LM the astronaut would make a northerly traverse starting from ALSEP (or EASEP) equipment bay location.

Astronaut operations associated with deployment of the ALSEP Seismic experiment are presented in Table 11.

TABLE 11.

ASTRONAUT OPERATIONAL SEQUENCE FOR SEISMIC EXPERIMENT DEPLOYMENT (ALSEP)

- Subject removes equipment, Apollo Lunar Surface experimental Package (ALSEP) and staff sections, from the Lunar Excursion Module (LEM) descent storage bay.
- Places ALSEP at suitable position.
- Assembles staff sections. The lower position of the staff contains a squib-fired thumper for inducing energy into the ground. The upper portion contains a compartment for the seismic cable. The cable is marked at 5-meter intervals.
- Plugs seismic cable into the ALSEP, and carries the staff during the operation.
- Walks 20 meters from ALSEP while paying out seismic cable.
- Kneels and pushes the second detector into the ground.
- Walks another 50 meters and pays out seismic cable.
- Kneels and pushes the third detector into the ground.
- The subject rises, turns around, and with the staff placed at the third detector, charges the capacitor in the staff and fires a squib.
- The subject then walks 5 meters back along the cable and places a second squib into position for firing, charges the capacitor in the staff, and fires the squib. This is repeated at 5-meter intervals to within 5 meters of the first detector (a total of 20 times.)

Electronics for recording the short times and arrival times will be contained in the ALSEP. The seismic line and detectors will weigh approximately 2 pounds. The thumper for inducing energy into the ground will also weigh approximately 2 pounds.

3.3.2 Stage II Missions

As indicated above, astronaut procedures for AAP mission must be general and representative due to the unavailability of precise mission planning information. A general mission plan for a geological mission to Copernicus was developed by the Geology working group for the 1967 Santa Cruz conference on Lunar Science. This plan is presented in Table 12.

Schleicher and Swann (1965) described a hypothetical scientific mission profile for a 14-day AAP mission and listed the following assumptions:

- 8-hour per day will be available for scientific work;
- each astronaut can operate outside the LM shelter for 6 continuous hours per day;
- astronauts will be trained in earth sciences;
- a three way voice link is maintained at all times between the two astronauts and earth;
- geophysical data will continually and automatically be telemetered to earth;
- astronaut activities will include LSSM control, monitoring of magnetometer and gravimeters, drilling of 1-meter holes, collection of samples and record data.

TABLE 12.

GENERAL MISSION PLAN - AAP MISSION TO COPERNICUS SINGLE LAUNCH SATURN V WITH EXTENDED LM (ELM). Two Man Crew - three-day stay

Day	Activities
1	Landing ELM Stabilization LFU Preparation 2 men 1 hour 1/6 g familiarization and LFU checkout 2 man 2 hour ALSEP emplacement 1 man 3 hour LFU Survey Sortie 1 to top of central peak; Photography, communications relay implant, sampling, gravimeter deployment 1 man 3 hour excursion to ELM to emplace 500 ft. geophone spread to obtain biological and rock samples
2	1 man 3 hour LFU sortie 2 Survey and sample crater floor and hill features Set seismic charges deploy gravimeter 1 man 3 hour lunar soil profiling at site close to ELM 1 man 3 hour LFU sortie 3 Survey and sample peak and base of second central peak deploy gravimeter 1 man 3 hour sample examination spectrometer sorting sample packing at ELM
3	1 man 3 hour LFU Sortie 4 examine and sample smooth floor material set seismic charges deploy gravimeter 1 man 3 hour survey local surface process at ELM 2 man 2 hour sample examination, selection, stowage, emplacement of scientific stations 2 man 1 hour departure preparation.

A later study by Schaber and Schleicher stated that each astronaut will devote 13 hours for 24 hour day to scientific and housekeeping duties. Of these, 7 hours will be spent in geologic activities. Astronauts will be able to walk approximately 3 km per day at an average of about 20 meters/minute.

CHAPTER IV.

RESEARCH ON HUMAN PERFORMANCE IN THE LUNAR ENVIRONMENT

As more knowledge of the lunar surface is gained and as lunar missions become more detailed in planning, an increasing emphasis has been placed on the determination of effects of the lunar environment on man performing operations associated with specific missions. The description of the lunar environment was presented in Chapter II of this report, while missions, mission equipment and operations were discussed in Chapter III. The present chapter will be concerned with presenting research findings on the general effects of the environment on human performance. The next chapter will identify problem areas associated with the capability of astronauts to perform specific operations in the lunar environment.

The description of research findings will be presented in two parts. First, the simulation techniques and facilities utilized in deriving the findings will be discussed. Then the findings themselves will be presented for such considerations as: vision, whole body movements, energy expenditures, perceptual-motor activities, spatial orientation, safety, and habitability.

4.1 Simulation Techniques and Facilities

Simulation techniques and facilities employed in deriving empirical data on human performance in the lunar environment are of two general types: gravitational simulations and visual simulations. Gravity simulators are primarily concerned with providing a gravitational force representative of that to be encountered on the moon (1/6 earth gravity). Visual simulators endeavor to simulate the lighting environment of the moon including surface albedo, retro-reflection of light, brightness of the surface, intensity of glare sources, etc.

4.1.1 Gravity Simulations

Since the early 1960's, scientists in governmental and industrial laboratories have been studying man's performance under lunar gravitational forces. These simulations can be grouped into three major categories: 1) parabolic flights in aircraft, 2) immersion in water, or some other medium, and 3) land-based simulations, where the subject still encounters 1 "g" forces. Each of these methods have specific advantages and disadvantages which will be discussed in the following paragraphs.

Parabolic Flights

This technique provides the highest fidelity simulation of the 1/6 "g" condition that presently exists. For a short period of time, the observer is subjected "both externally and internally" (R. Shavelson, 1968) to gravitational forces such as those found on the lunar surface. One of the shortcomings of this technique is that it only allows for up to one minute of testing time per parabolic maneuver. This is not long enough for detailed evaluations to be conducted. A second disadvantage is that the "g" loading is not consistant during a flight nor is it directly applicable to the lunar mission in terms of sequence of "g" loadings. In actual earth-moon flight, the astronauts will be subjected to slightly more than 1 lunar "g" for less than one hour prior to touch down. Hence, the time sequencing is 72 hours of weightlessness, one hour of approximately 1/6 "g", and then touch down on the lunar surface. With parabolic flights, the sequence is 2+ "g's" reducing to 1/6 "g" (for approximately 40 seconds), returning to 2+ "g's" before becoming 1 "g" after recovery from the parabolic maneuver to a normal flight path.

In summarizing parabolic flights as a simulation technique, it can be concluded that while it produces the highest degree of fidelity in terms of 1/6 "g" simulation, it can only be presented for a period of time less than one minute. It is, therefore, useless in terms of medical evaluations for physiological trends, and can only be used for short-term psycho-motor performance evaluations. The results of such an evaluation can be questioned due to environmental factors ("g" forces) present prior to the 1/6 "g" segment of the parabolic trajectory.

Immersion Techniques

The most common technique of simulation using immersion is via water immersion. With this method, the subject is placed in a liquid medium which displaces 5/6 of the subject's weight. With this technique, partial or total submersion is possible for extended periods of time.

Because of the time factor that the subjects can remain in the water tanks, this technique is extremely useful in obtaining medical base-line data. This is primarily data pertaining to physiological functioning over periods of time by a body in a resting condition. More recently, this technique has been used in the study of man's capabilities in space, determining man-machine interfaces, obtaining design data, and in providing pre-mission training.

Water immersion partially simulates the physiological effects of reduced gravity environments. It creates many of the physiological effects of reduced gravities, particularly with respect to musculoskeletal, cardiovascular systems and sleep. problem with some water immersion studies is that this technique can produce hydrostatic side effects that would not typically be found in a reduced gravity environment. To counter this side effect, some investigators (White, Nyberg, and White, 1966) have used silicone oil as the immersion medium, since it has a viscosity more closely resembling body fluids and does not seem to induce the hydrostatic effects. The above mentioned investigators found that after ten days of immersion, the subjects being tested still did not indicate hydrostatic side effects. They also report studies where the subjects immersed in this liquid medium have been investigated for as long as 30 days. As stated by Gaume and Kuehnegger (1962) water suspension does not produce true weightlessness, but it does remove the weight of the body from the skeletal structure and obviates the need for using anti-gravity muscles to hold the body erect.

While there are limitations imposed by hydrodynamic drag and planning forces, hydrostatic simulation of reduced gravity environments permits the pressure suited subjects to operate in six degrees of freedom while providing total support for the body appendages. The simulation is not limited by supporting cables or attachments to the subject's body and is relatively insensitive to changes in the center of gravity. Time is not a limitation since operation can be extended to several hours or longer with sufficient breathing gas.

Land-Based Simulation Techniques

Bed rest is another means of simulating some of the conditions associated with space flight and the lunar environment. The orthostatic changes in heart rate, blood pressure, and muscle tone which have been noted to occur in association with space flight likewise occur in bed rest. This provides an excellent means of studying nutritional requirements and bone mass changes for long-range space missions. Protective measures are being developed to overcome the cardiovascular deconditioning that has been observed. Bed rest studies require the use of hospital-type facilities staffed 24 hours a day by medical specialists. Bed rest has the advantage of avoiding the hydrostatic side effects of water immersion on circulation and respiration, but has the disadvantage of the lack of weightlessness produced by water buoyancy. It should be noted that bed rest studies have been conducted mainly in terms of a weightless condition such as that found in space. These data have to be extrapolated to become applicable to lunar environmental conditions.

The most popular simulation techniques presently in use in this country could be classified as land-based 1 "g" techniques. In this category one would find counterbalance simulators, inclined plane simulators, and more recently, the Lockheed-type Negator spring simulation facilities. As Shavelson (1968) has described them, each method has inherent problems. In the counterbalanced simulation, the subject is placed into a suspension rig and counterbalancing weights are applied so that 5/6ths of the subject's weight is relieved. This is the same principle employed in the negator spring simulation, except that negator springs are used instead of a counterbalancing weight. In the inclined plane situation the subject is supported horizontally by cables at the head, chest, hips and legs, and stands on a plane inclined 9 degrees from the vertical. The cables are connected to an overhead low friction trolley. Disadvantages of this technique include the fact that it does not simulate physiological effects of lunar gravity, that it cannot be used to study lateral movements, and that the overhead trolley restricts locomotion due to friction and slow reaction time.

In negator spring simulation a lifting force of 5/6 of the subject's weight is exerted by negator springs and a spring motor capable of applying constant torque to a shaft regardless of rotational displacement. The shaft is attached to the subject via a cable and harness.

These simulation techniques are most effective when the subject remains in a vertical plane. Usually these rigs are concerned with the ability of the subject to perform specified actions under the 1/6 "g" condition. In fact, however, the 1/6 "g" condition exists only in relation to weight in the vertical axis of the torso. The arms and legs of the subject are still effected by earth's gravitational field. This is also the case in terms of the subject's internal organs. The most critical disadvantages of these systems are that the operator must work the rig so as not to introduce any physical handicaps with cables, wires, structures, etc. Most rigs are cumbersome and must be compensated for by the subject. In addition, the mechanical lifting device and trolley mechanisms it rides on impart resistive and inertial forces that are artifacts of the simulation techniques employed. The negator spring simulator at Lockheed seems to be less prone to these faults. One of the newer modifications of this technique using negator springs and magnetic air bearing supports has been developed by Case Western Reserve University (1968). This technique should be valuable in reducing the undesirable side-effects of the trolleys, since translational motion is assured with virtually no frictional restraint.

The limitations in the design of the gravitational environment simulators, and the fact that in general they do not totally simulate the complete range of environmental factors such as those that will be found at the lunar surface, limits the applicability with which they can be used. While little has been done to compare results obtained with different simulation techniques, Robertson and Wortz (1968) reported that metabolic rates were found to be significantly lower with the six degree of freedom gimballed rig than with the inclined plane simulator. These investigators conclude that the level of validity of the various simulation techniques has yet to be demonstrated. In discussing fidelity requirements for lunar surface simulations, Lehr (1968) stated unequivocably that facilities to provide high fidelity do not exist today.

4.1.2 Visual Simulations

As emphasized by Taylor (1964), predictions of visual performance on the moon should not be made without validation in a realistic environment wherein representative lighting conditions are simulated. For lunar simulation to be operationally valid, it must incorporate the effects of directional reflectance, lack of a scattering atmosphere, and glare (Allen, 1967).

The majority of what is known today concerning human visual performance in the lunar environment has been inferred from photometry studies which are primarily concerned with describing the quantity and quality of lunar lighting. From the results of these photometric assessments, analytical evaluations have been conducted to predict the range of human performance in this lighting environment.

One example of an attempt to acquire empirical data reflecting human visual performance in the lunar lighting environment was reported by Lewis and Wheelwright (1965). In this study a helicopter with a simulated Lunar Module (LM) window was used to fly LM landing trajectories from 1,000 ft. altitude to the surface. Fifty flights were made over homogeneous terrain and observers wore neutral density filters to simulate lunar brightness levels ranging from one-fourth full earthshine to full earthshine. This study was conducted at the Pisgah Crater lava flow at the sourthern end of the Mojave Desert. This lava flow, located at twenty-nine palms, California, has as area of 36 square miles and an elevation of from 1,886 to 2,543 feet above sea level. The area was selected because it's terrain simulated the known lunar features of homogenety, monochromatisity, low albedo, absence of vegetation, and absence of man-made structures.

A second attempt to empirically assess human performance in a lunar lighting environment was described by Freeberg and Cook (1964). These investigators constructed a three foot square model of the lunar terrain which simulated the albedo of the surface and presented features representative of those to be viewed at altitudes of from 1,000 to 50,000 ft. above the surface. Subjects were presented with photographs taken of one foot square sections of the model under carefully controlled angles of illumination and observation. The subjects were also presented with one foot square sections of the model under different lighting and viewing angles and asked to match the area of the model with the photograph of the same area.

Except for references to exploratory research of visual capabilities being conducted on lunar terrain simulations, the literature on human performance in the lunar environment contains few research reports on studies of effects of lunar lighting on visual performance. Much more emphasis has been placed on developing a valid simulation of lunar gravitational effects than lunar lighting effects despite the fact that the lighting situation may be more dramatically novel and may have more of a degrading effect on locomotion performance.

4.2 Research Results

The findings reported from simulation studies and analytical investigations concerning human performance in the lunar environment are presented in this section. These findings are presented for visual performance, whole body movement as encountered in walking, running, vehicle ingress/egress, etc., energy expenditures expressed as metabolic rates for different activities, perceptual-motor performance, spatial orientation, astronaut safety, and habitability.

4.2.1 Visual Performance on the Moon

An area of great concern to scientists involving themselves with extra-terrestrial space travel is the astronauts visual perceptual capabilities. Many of these investigators believe that the problems associated with the visual system working reliably in the space environment are formidable. Howe and Gregory (1968) list some of the problem areas as being: "the possibility that under conditions of low redundancy of visual information there may well be occasions when judgments of size, distance or velocity are made against such references and when the resulting action will be wrong since the visual judgment is arrived at in an unusual way." They conclude that a space ship's window could induce such errors since it might serve as a frame of reference that is irrelevant. This irrelevance is caused by the prevention of constancy scaling which is required for accurate perception.

Brown (1967) indicates that one of the major visual problem areas of men on the lunar surface will be the excessively high contrast ratios and the ranges of illumination that the astronaut will have to cope with. This environment does not have an atmosphere as earth does, hence the scattering of light will be different. These effects combine to create a visual environment completely new to the astronaut. This lack of familiarity will cause additional problems. The author states that "the judgment of size, when the nature of the object viewed is unknown, is extremely difficult. Photographs of the surface of the moon illustrate that it has a miliary appearance in terms of the distribution of visual angles which represent diameters of craters over a large range of distances. There is, thus, a range of crater sizes such that visual pattern may look very similar from relatively near and far vantage points."

Another major problem area revolves around the intensity of the sun in the lunar sky. In an attempt to reduce the probability of retinal damage, the astronauts on the initial lunar flights have been instructed to wear their sun visor in the down position all the time. As Iribe and Lieske (1966) contend, this is not always the most desirable situation, since a filter can produce situations where there is an insufficient transmission of illumination from the area where a task is to be attempted. This obviously will lead to situations where the task cannot be completed without the aid of auxiliary illumination. They note that the lunar environment is strenuous enough on the visual system and that certain viewing angles can so reduce the available illumination that familiar objects may be difficult to recognize or may vanish altogether (Iribe and Lieske, 1966).

On Christmas Eve, 1968, during their ninth revolution of the moon, Apollo 8 astronauts James Lovell, William Anders, and Frank Borman described their visual perceptions of the moon. Astronaut Borman saw the lunar surface as resembling clouds of pumice stone. Astronaut Lovell described small bright impact craters that dominated the surface and reported that the surface was entirely devoid of color. Astronaut Anders described the lunar horizon as very stark with a sharp contrast between the pitch black sky and the light moon. Such were the reported observations of the lunar scene the first time that man was physically within 70 miles of the surface. It can be inferred from their comments that the astronauts were not overly concerned with variations in brightness due to changes in viewing angle. It is implicit in their comments that the moon, from their vantage point, was more or less uniform in its brightness. The smallest resolvable terrain features, assuming ideal viewing conditions and a one-minute of arc threshold for resolving visual detail, when viewed from 70 miles, is 125 feet. It, therefore, is probable that objects, and their shadows, which were smaller than 125 feet were not seen by the astronauts. Hence, their view of the moon was comprised of relatively larger features, and their perceptual of light distribution was still more global than local.

Information concerning research results reporting human visual capabilities in the lunar environment is presented below. This information is presented for such visual factors as visibility and lighting, visual acuity, distance and depth, and form and pattern.

Visibility and Lighting

The most important determiners of visibility are the available light, the viewing angle and surface contrast. Available light on the moon can be from one of two different sources - the sun and the earth. The average illumination of the lunar surface by the sun is 12,000 ft. c. and by the sunlit earth, 1.25 ft. c.

Since the moon reflects seven percent (7%) of incident light, the average maximum brightness of the moon under conditions of full sunshine and full earthshine are 840 ft. L and .0875 ft. L. respectively. The effect of viewing angle on light delivered to the eye is presented in Table 13 for two illumination conditions - i = 0° and i = 70° (i= the angle of incident light).

TABLE 13.

PERCENTAGE OF MAXIMUM BRIGHTNESS FOR DIFFERENT VIEWING ANGLE

	i = 0°			i = 70°		
Viewing Angle	% of Maximum	Sunlight in Ft.L.	Earthlight in Ft. L.	% of Maximum	Sunlight in Ft. L.	Earthlight in Ft. L.
0°	100	840	.0875	11	92.4	.0096
10°	81	680	.071	13	109.2	.011
20°	60	504	.053	14	117.6	.012
30°	49	412	.043	18	151.2	.016
40°	42	353	.037	24	201.6	.021
50°	37	311	.032	34	286.0	.030
60°	33	277	.029	54	454.0	.047
70°	32	269	.028	100	840.0	.0875
80°	30	252	.026			

In Table 13, the first illumination condition ($i=0^{o}$) refers to the situation where the incident light rays are normal to the surface; and, the second condition ($i=70^{o}$) is had when the angle of incident light is 70 degrees from the normal. This latter lighting condition is close to that planned for the first lunar landing (sun angle of 74^{o}). Taylor (1966) has noted that the highly directional nature of the illumination will, especially at low angles, combine with the low surface reflectivity to produce wide extremes in the appearance of terrain. The third important determiner of visibility, contrast, depends on the variability of brightness of the lunar scene. The primary contrast condition will be between illuminated areas and shadow, which Roth (1968) predicts will be very black leading to extremely high contrasts. This high contrast is due to the lack of lunar atmosphere resulting in an absence of diffused light. The brightness of shadowed areas has been set at 10^{-6} ft. L. by Taylor (1966), who also attributes the high contrast conditions to the lack of atmospheric scattering.

As indicated in Figure 3, 10^{-6} ft. L. approximates the absolute threshold of seeing, hence, we can expect little or no detail of the shadowed area to be perceptible. The proportion of lighted areas to shadowed areas depends on the roughness of the terrain and the angle of incident light. At a 45^{o} angle of incidence the length of shadows will equal the size of the objects casting the shadows. With an angle of incidence of 70°, shadows will be 2.75 times as long as the objects. A surface area having a density of one foot high features (rocks) such that each feature is located within 2.75 feet of another feature could be entirely in shadows. The extent of shadowed terrain perceived depends on the viewing conditions. When looking toward the light source (sun or earth), shadows will be more prominent since they will be located on the observer side of the objects casting them. With the sun behind the observer, the shadows will be cast on the opposite side of the objects.

Due to the extreme backscattering of light from the lunar surface, the brightness conditions also vary radically depending on whether the observer is looking toward or away from the sun. With an angle of incidence of 70°, an observer with his back to the sun and with an 85° viewing angle still will perceive 78 percent of the maximum surface brightness, while if he were to retain the 85° viewing angle and turn toward the sun, he would receive only 3 percent of the maximum luminance. This represents a decrease of from 655 ft. L for the "sun behind" situation to 25 ft. L. surface brightness for the situation where the observer looks toward the sun.

Another factor which complicates this situation is that when the astronaut views lunar terrain in a direction toward the sun, the sun could conceivably be in the field of view. As indicated by Roth (1960), with an apparent luminance of about 6.4×10^8 ft. L and subtending one-half degree, the sun constitutes a glare source of tremendous magnitude. Roth concludes that "if man on the lunar surface of must operate with the solar disc in his visual field, it is imperative that suitable protective devices be provided which will prevent discomfort or temporary or permanent visual disability". (Roth, 1968, pp. 2-109). A problem with this approach is that the viewing situation which requires the use of filters, looking toward the sun, is the same wherein minimal light is delivered to the eye and maximum shadowed area is perceived. By filtering out 90 percent of the available light the apparent brightness of the solar disc is reduced from 6.4×10^8 to 6.4×10^7 ft. L. However, the brightness of a lunar area with an 85° viewing angle is also reduced from 25 ft. L to 2.5 ft. L.

Roth (1968) continues his analysis of the situation by stating that while it has been argued that man will always operate so as to avoid looking into or near the sun, the probability exists that accidental exposure will occur. The effects of inadvertant visual acquisition of bright sources such as the sun were reviewed by Severin et al. (1962). These investigators calculated the time to recover visual sensitivity following exposure to bright light. These results, as reported by the authors, indicate that for a source of brightness comparable to that of the sun as seen from the moon, 134,000 lux, the recovery time ranges from .19 minute for small pupils to .27 minute for large pupils. Therefore, it should take from 11 to 16 seconds to reacquire a test patch of .06 ft. L brightness following illumination of the eye by the sun.

The probability is low that viewing of the sun for short durations will result in retinal burns. DeMott and Davis (1959) have stated that illumination of the eye of 240,000 lumens/ft.^{2} represents the probable level required for retinal burns. These investigations also report that this energy must be delivered at a rate of at least 0.7 cal/cm^2/sec. As indicated in Table 13, the illuminance of the sun is 12,000 ft. candles or lumens/ft.^{2} and the energy rate is 2 cal/cm^2/min or .03 cal/cm^2/sec.

When the earth or sun is not in the field of view, the sky above the horizon will appear essentially black. It has been stated by Taylor (1966) that in this situation the adaptive capabilities of the man on the lower surface may be taxed and that his visual performance under such conditions cannot confidently be predicted from existing data.

During early stages of Apollo mission planning, much consideration had been given to the visual capabilities of man under conditions of full earthshine since the original landing site was to be the sub-earth point. A study conducted by Lewis and Wheelwright (1965) stated that landing operations should not be conducted when surface brightness is less than .009 ft. L. and that levels between .009 and .04 ft. L. make some operations unsafe. Subjective reports indicated that a high degree of confidence was not attained until a brightness of .06 ft. L. was reached. Jones (1967),also employing subjective reports of confidence as his primary dependent variable, indicated that under certain conditions earthshine is adequate for lunar operations. A study was conducted of the effects of viewing angle and illumination angle on recognition of simulated lunar terrain features under earthshine lighting conditions (model brightness of .1 ft. L) (Freeberg and Cook, 1964). Results of this study indicated that performance in matching features viewed on the model with photographs was most degraded for low angles of incidence (less than 15°) where shadows were minimal and for higher angles of incidence (greater than 60°) where shadows were longer. The performance was best as the angle of incidence approached 30° from normal.

Visual Acuity

Visual acuity refers to the ability to discriminate visual objects and is calculated as the reciprocal of the visual angle subtended (in minutes of arc). The types of visual acuity and values reported with each are presented in Table 14. The variables affecting visual acuity have been listed by Lit (1968) as:

- Target luminance;
- Contrast between target and background;
- Wavelength of light;
- Duration of exposure;
- State of adaptation of the eye;
- Intermittency of light;
- Pupil size;
- Accomodation of the lens of the eye;
- Object orientation;
- Eye movement;
- Target movement.

TABLE 14.

TYPES AND VALUES OF VISUAL ACUITY

TYPES	CONDITIONS AND VALUES
Minimum perceptible	Luminous point (e.g.) star - no lower limit
	Dark square on bright sky - 14.2 sec.
	Thin wire on bright sky - .43 sec - 1 sec.
Minimum separable	Gap between luminous points on black background - 180-200 sec.
	Lines of a grating - 64 sec.
Minimum distinguish-able	Gap in landolt c at 10,000 ft. - 24.4 sec.

In a series of studies designed to demonstrate the feasibility of a lunar landing under earthshine conditions, Malone (1964) calculated the smallest object perceptible at different altitudes and lunar longitudes. From these studies, it was reported that at 0° phase angle (full earthshine at new moon) and with an object-background contrast of - .93 (shadow viewed against earthshine illuminated terrain) a 1 foot object was perceptible at 1,000 ft. altitude, a 2 foot object at 2,000 ft., etc. For an astronaut standing on the lunar surface, the smallest perceptible object associated with different viewing angles is presented in Table 15. These data assume earthshine conditions with the incident earthlight normal to the surface. The brightnesses of the points associated with each viewing angle are repeated from Table 13. The data of Table 15 also assume a 50 percentile astronaut in terms of eye height above the surface - 5.5 feet.

TABLE 15.

SMALLEST PERCEPTIBLE OBJECT AT DIFFERENT VIEWING DISTANCE

Viewing Angle	Distance from astronaut (ft.)	Viewing Distance (ft.)	Available Earthlight in ft. L.	Visual Angle (minute)	Smallest perceptible Object in ft.
0°	0	5.5	.0875	1.41	.0023
10°	.97	5.6	.071	1.59	.0026
20°	2.0	5.85	.053	1.85	.0031
30°	3.2	6.35	.043	2.0	.0037
40°	4.6	7.2	.037	2.13	.0044
50°	6.6	8.6	.032	2.17	.0050
60°	9.5	11.0	.029	2.27	.0069
70°	15.0	16.2	.028	2.27	.0100
80°	31.2	32.3	.026	2.33	.0200

Martindale (1966) reports that an approximate 5 percent improvement in acuity has been found in viewing through a vacuum as compared with viewing through an atmosphere. Russian investigators reported that visual acuity declined with the onset of weightlessness but in some cases returned to normal or nearly normal after further exposure. It was further reported that visual resolution of the cosmonauts during orbital flight has almost unchanged with small variations being observed which did not exceed experimental error. Finally it was reported that verbal reports of the cosmonauts of observations made on earth objects indicated that visual acuity exceeded the norms, especially with linear objects as roads or railroad tracks (Soviet Bioastronautics, 1968). Similar results were obtained from American orbital flights. Astronaut L. Gordon Cooper's visual acuity on his Mercury Mission was measured at 20/12 on the Snellen scale. Astronaut Edward White in Gemini 4 concurred with Cooper in reporting perceived roads, boat wakes, airfield runways, and smoke from buildings from orbital altitude of over 100 miles. Such observations demonstrated an ability to resolve a half-minute of arc or less (Deutsch, 1965).

A description of the development of the Gemini Visual Acuity Experiment (S-8/D-13) and an account of experimental procedures and results from the Gemini flights V and VII was presented by Duntley et al. (1968). This experiment was designed to test the hypothesis that visual acuity of astronauts in orbit would not be different from that measured under normal circumstances on earth. Two types of tests were conducted, one of which was involved with the use of a vision tester to compare preflight and inflight acuity measurements. A second test involved the resolution from the orbital altitude of targets located on earth.

Results of the vision tester experiments are presented in Tables 16 through 19 which compare Gemini preflight and inflight performance under two contrast conditions, while Tables 20 through 23 involve the comparison of the first 4 with the last 4 experimental trials. Based on an evaluation of these data, Duntley et al. (1968) conclude that the visual performance of crews was not affected by spaceflight. They concluded this despite the finding of significant difference between preflight and inflight results for Cooper in the high contrast condition, and Borman and Lovell in the low contrast condition. Thus, three out of a total of eight comparisons demonstrated statistically significant results at either the .01 or .05 levels.

From an analysis of out-the-window sightings made on Gemini Missions V and VII, the investigators also concluded that orbital flight has no effect on visual acuity.

Perception of Distance and Depth

According to Kopal (1964), due to the large curvature of the relatively small lunar globe, all but the nearest peaks will be concealed. Peaks of 3,000 meters in elevation will disappear

TABLE 16.
VISION TEST (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-VII	*C = -0.9		C = -0.21	
BORMAN	GROUND	SPACE	GROUND	SPACE
Number --------	11	14	11	14
Mean ----------	20.0	19.9	8.45	8.4
Standard deviation ---------	1.3	1.6	.78	1.7
t -------------	0.12		0.017	
$t_{0.05}$ ---------	2.07		2.07	
F -------------	1.49		4.74	
$F_{0.05}$ ---------	2.89		2.89	
$F_{0.01}$ ---------	4.66		4.66	

* contrast conditions

TABLE 17.
VISION TESTER (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-VII	C = -0.9		C = -0.21	
LOVELL	GROUND	SPACE	GROUND	SPACE
Number ---------	9	14	9	14
Mean -----------	20.9	20.0	9.1	9.1
Standard deviation ---------	1.4	1.6	.74	1.4
t -------------	1.29		0.073	
$t_{0.05}$ ---------	2.08		2.08	
F -------------	1.17		3.64	
$F_{0.05}$ ---------	3.26		3.26	
$F_{0.01}$ ---------	5.62		5.62	

TABLE 18.
VISION TESTER (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-V	$C = -0.9$		$C = -0.21$	
COOPER	GROUND	SPACE	GROUND	SPACE
Number ---------	7	9	7	9
Mean -----------	17.6	18.4	8.6	8.3
Standard deviation ---------	2.3	.96	1.3	1.4
t -------------	0.96		0.31	
$t_{0.05}$ ---------	2.14		2.14	
F -------------	6.12		1.02	
$F_{0.05}$ ---------	3.58		3.58	
$F_{0.01}$ ---------	6.37		-----------	

TABLE 19.
VISION TESTER (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-V	$C = -0.9$		$C = -0.21$	
CONRAD	GROUND	SPACE	GROUND	SPACE
Number ---------	7	9	7	9
Mean -----------	20.7	20.7	9.7	8.6
Standard Deviation ----------	2.7	1.7	1.2	2.0
t --------------	0		1.13	
$t_{0.05}$ ----------	2.14		2.14	
F --------------	2.79		2.43	
$F_{0.05}$ ----------	3.69		4.82	

(Duntley et al., 1968)

TABLE 20.
VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-VII	C = -0.9		C = -0.21	
BORMAN	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.0	20.0	8.0	9.0
Standard deviation	1.4	1.4	1.3	1.8
t	1.00		0.91	
$t_{0.05}$	2.31		2.31	
F	1.00		2.00	
$F_{0.05}$	6.39		6.39	

TABLE 21.
VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-VII	C = -0.9		C = -0.21	
LOVELL	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.8	20.4	8.8	9.2
Standard deviation	1.3	1.5	1.2	1.6
t	0.60		0.91	
$t_{0.05}$	2.31		2.31	
F	1.27		1.88	
$F_{0.05}$	6.39		6.39	

TABLE 22.
VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-V	C = -0.9		C = -0/21	
COOPER	First 4	Last 4	First 4	Last 4
Number ----------	4	4	4	4
Mean ------------	18.2	18.8	8.5	8.5
Standard deviation -----------	.83	1.1	.87	1.8
t ---------------	0.68		0	
$t_{0.05}$ -----------	2.45		2.45	
F ---------------	1.73		4.33	
$F_{0.05}$ -----------	9.28		9.28	

TABLE 23.
VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-V	C = -0.9		C = -0.21	
CONRAD	First 4	Last 4	First 4	Last 4
Number --------	4	4	4	4
Mean ----------	21.3	19.5	8.8	8.75
Standard deviation ---------	1.5	1.1	2.8	.83
t -------------	1.64		0	
$t_{0.05}$ ---------	2.45		2.45	
F -------------	1.96		11.19	
$F_{0.05}$ ---------	9.28		9.28	
$F_{0.01}$ ---------	-----------------		29.5	

below the horizon at a distance of 100 Km. This situation, in the investigator's view, lends to a loss of local orientation (Kopal 1964).

The foreshortening of the lunar horizon could have a great effect on the astronaut's performance in that distance judgements, conditioned by Earth experience and referents, might be grossly overestimated on the Moon. This is true not only for judgements of absolute distances, but also for relative distances where the horizon is used as a reference. The use of the foreshortened horizon as a basic reference point would also lead to over-estimations of the size of objects. If this is demonstrated to be a function of learning, it might be possible to simulate the foreshortened horizon in laboratories on the Earth, and train the astronauts in size and distance estimations in advance of lunar missions.

Lichtenstein and Suit investigated techniques for determining visually the altitude of a spacecraft above the lunar surface. One technique required the subject to match calibrated curved arcs to the projected lunar horizon curvature. The second method required a measurement of the visual arc subtended by known surface features, such as craters of known diameter. The results of the study indicated that using the matching technique the average error was large, ranging from 6 to 36 miles with a standard deviation of 28 miles. The surface feature approach was more accurate when a feature was viewed from directly above.

In this situation the standard deviation of errors was one third as large as reported with the matching technique (Lichtenstein and Suit 1967).

Brown (1967) stated that on an unknown planet the judgement of size is extremely difficult when the nature of the object viewed is unknown. Photographs of the surface of the moon illustrates that it has a very similar appearance in terms of the distribution of visual angles which represent diameters of craters over a large range of distances. There is, thus, a range of crater sizes such that the visual pattern may look very similar from relatively near and far vantage points.

In defining the effects of a lack of atmosphere on visual performance, Taylor (1966) indicated that the atmospheric haze is habitually used on earth to estimate distance and size. This haze is totally absent in the lunar environment, hence judgements of size and distance will probably require the use of some aiding device, as a theodolite or range finder. This investigator goes on to state that the sky above the horizon will be essentially black which lends to a variable adaptive state. The author concludes that visual performance under such condition cannot confidently be predicted from existing data (Taylor 1966). Kopal (1964) inferred that the lack of air and the transparency of space would lend to gross underestimates of distance. Letko et al (1966) also concluded that the lack of an atmosphere on the moon will result in an increase in brightness contrast which will affect depth perception. Vincent et al (1968) determined the just noticeable difference for distance in a space environment. The research utilized an optically simulated large target located in a textureless environment at distances along the saggital plane out to 12,800 feet. The value of $\Delta D/D$ varied from less than 3 percent at 200 feet distance to about 7 percent at 12,800 feet. These results confirmed the power function between distance threshold and observation distance.

Perception of form and shape

On the Moon, the astronaut will encounter higher luminance levels than on Earth, however, these levels appear to be within man's operating tolerance. Problems arise when the visual stimuli are perceived in a rarefied atmosphere that does not diffuse light. In such an atmosphere, those portions of the scene in direct sunlight will appear to be unusually bright, while the portions not in the sunlight will appear to be black. This allows for the lesser degree of shadow effects than encountered on earth.

The ability to make judgements with the assistance of shading and shadows is an important cue in our everyday perceptual world. On the moon, shaded areas will appear to be very black. There will be sharp boundaries between light and dark areas, which means that not only will contrasts be extremely high, but that the range of the contrasts will be greater than usually found on earth. This will lead to a limitation of the individual to perceive shapes correctly.

The highly directional nature of lunar illumination will, especially at low angles, combine with the low average surface reflectance to produce wide extremes in the appearance of terrain (Taylor 1964).

The Moon appears to have a drab and colorless surface. The predominance of darker colored surface features accounts for the reduced albedo, which is approximately that of bauxite found here on Earth. Most of the visible radiation impinging on this surface is absorbed, and that which is readmitted into the environment is minimal. The texture of the lunar surface probably resembles that of damp sand. This structure, which is a loose molecular bonding with a finely pitted surface, reflects light back along the angle of incidence. This coupled with a lack of atmospheric dispersion, limits the partial shadow effects which are used as primary visual cues in the terrestrial environment.

4.2.2 Whole Body Movements

The ability to conduct lunar exploration depends on the astronaut's visual capability and also on his capability to maneuver himself about the lunar surface. In early Apollo and Apollo missions this exploration will be conducted by means of self locomotion, i.e., walking about the surface. The factors of the lunar environment which could significantly affect self locomotive performance are gravity and topology. Of these considerations primary emphasis, in terms of empirical evaluations by simulation, has been placed on the gravity condition.

In a comparative study of walking and running gaits in earth and simulated lunar gravity, Hewes et al (1966) concluded that there will be significant differences between earth and lunar gaits and that these differences may have an impact on space suit design and mission planning. The most comfortable lunar gait was found to correspond to that requiring the least total expenditure of work. This natural lunar gait comprised a lope at about 10 feet per second (3 m/sec) which is much faster than the natural earth walking gait of about 4 feet per second (1.2 m/sec.) Such was the conclusion of Magaria and Cavgna who assumed that locomotion on the moon may not even be possible via the walking mode, and will probably be similar to the running mode. These investigators also portulated a jumping (or loping mode) for higher speed. In the earth environment the shift from walking to running occurs at the critical speed of approximately 5.3 miles per hour. This critical speed should be considerably less for the lunar environment.

Using the 1/6 "g" suspension rig, Spady and Krasnow (1966) found that "in the pressurized suit the comfortable lunar walking pace was faster than that for Earth walking, but the maximum lunar running speed for the short distance used in this study was slower by about 40 to 50%..." They felt that this was the result of the lower traction found in the 1/6 g environment.

Findings reported by Hewes et al (1966) indicated that walking and running speeds should be greater on the moon than on the earth by approximately 60% and these actions should involve fewer steps. The subject's posture and appendage movements differed for earth and reduced gravity conditions.

Three subjects participated in this study. They were dressed in loose-fitting, summer-weight cotton flying coveralls and wore crepe-rubber soled boots. Recordings of the various trials were via motion picture recordings, and stop watch recording.

In the analysis of the data, several factors should be noted:

The study was conducted on 3 "shirtleeved" subjects. This is not a practical analysis since men on the lunar surface (after leaving the LM or some other form of lunar shelter) must be encapsulated in a space suit (which restricts motion greatly).

The differences in the surface structure and topology of the earth and the moon were not incorporated into this study. Such differences could significantly affect results citing astronaut performance of lunar exploration activities.

Under the ideal testing conditions that existed in their simulation (moderate temperature, well-cooled suit, no Portable Life Support System (PLSS), a hard-consistant walking surface), Spady and Krasnow (1966) reported that five subjects "could walk, run, and perform both vertical and broad jumps under both gravity conditions." The authors did note that these preliminary results should be considered in light of the above mentioned constraints. They then go on to state that "an evaluation of the test results indicates that an explorer wearing a pressurized space suit on the moon will be able, with practice, to walk and run provided, of course, that the terrain is relatively firm and not too rough. He should also be able to perform many other self-locomotion tasks such as jumping and climbing and will be able to out-perform his earth counterpart with the exception of body motions requiring rapid accelerations along the surface such as running which requires traction." (p.15)

The subjects could jump vertically 6 to 7 times higher, and perform standing broad jumps 2 times further at lunar gravity than at earth gravity.

The experiments obviated any possibility of astronaut lateral motion due to the testing rig (inclined plane) and any shifting of the c.g. due to the absence of the PLSS. These conditions were not included as potential degradational factors affecting man's performance on the lunar surface. Five subjects were used in this study. While this number is adequate for psycho-physiological studies, it is questioned whether it is large enough sample for studying performance parameters.

Hewes (1967a) assumed that the maximum heat dissipation rate for the space suit system will be 2,000 BTU/hr. Using this rate as a limiting criterion, the maximum possible speed is indicated to be about 7 mph (11 kmph) for the lunar explorer, which can be sustained for periods up to 30 minutes. The sustained locomotive speed on the lunar surface can be from 4 to 5 times that encountered on earth.

For long range activity, i.e., distances of 8 miles (12.8 km) or greater, the locomotive speed must be regulated to avoid operational limitations. For short range activity of 4 miles or less there is a fairly large latitude in selection of locomotive speeds which will not produce fatigue. For these short ranges the limiting factors are life support capacity and heat disipation capability (Hewes 1967a).

The lunar explorer is able to cover a distance of 3 miles (4-8 Km) at about 9 times the speed the same distance is covered on earth, and consequently, in 11 percent of the time. The above results led the investigator to recommend that for explorations of less than 6 miles (9.6 Km) it is more efficient in terms of time and system load not to stop and rest. For longer excursions it is advisable to periodically stop to rest. (Hewes 1967a)

Spady and Harris (1968) reported that the maximum running speed achieved by subjects in lunar gravity was 15.5 fps in an unpressurized suit, and 12.5 fps in a suit pressurized to 3.7 PSIG. These investigators also found that carrying loads up to 500 lbs did not appreciably affect the maximum running speeds. Increasing the load carried from 100 to 500 lbs. caused an increase in stepping rate of approximately 30 percent at 7 fps and 50 percent at 11 fps. Subjective reports noted in this study indicated that the 500 lb. load seemed to approach the maximum load carried while sprinting (Spady and Harris 1968).

Using the Langley Research Center reduced gravity simulator, Letko (1966) reported results indicating that with little practice subjects were able to maintain static equilibrium, walk, run, and perform other self locomotive tasks in simulated lunar gravity. These findings led the investigators to conclude that astronauts will find it relatively easy to adapt to the lunar condition.

The rates that these experiments reported for walking, loping, and sprinting in earth and simulated lunar gravity conditions are presented below.

In a review of lunar self locomotion studies conducted at Langley Research Center, Hewes (1967b) cited findings of a reduction in the number of steps per second required for a given locomotion speed in the lunar environment. This reduction was assumed to be due to the capability of the subject to take a longer stride in the lunar gravity condition. This investigator also cited results indicating that for any time period the lunar

COMPARISON OF RATES IN 1 g AND
1/6 g CONDITIONS (LETKO et al 1966)

	1 g	1/6 g
Walking speed	4 fps	4.1 fps
Loping speed	10 fps	10.5 fps
Sprinting speed	19.8 fps	13.1 fps

explorer can cover about 4 times the distance as his earth counterpart. (Hewes 1967b) Roth (1966) also reported evidence to support the conclusion that as the body weight is reduced the stride is elongated and the number of steps decreased for any distance covered.

Simulation studies concerning man's locomotive abilities on the moon have also been performed in 0 "g" and 1 "g" environments. Simons, Walk and Sears (1965) conducted studies of the mobility of subjects wearing pressure suits in weightless and 1/6th "g" conditions. They concluded that the motions of the subjects in reduced gravity conditions will probably differ significantly from similar actions performed on earth. For this reason they stated that "there is a good reason to suspect that man will choose many new motions for performing other tasks in low-gravity environments." The results of this study indicated that in 0 "g" and 1/6th "g", suited motions of the subjects required about 30% more time than under normal gravity conditions. When all motions were accounted for, 35% more time was needed in 0 "g" than in 1/6th "g" environments. This might be interpreted as indicating increases in time being dependent upon a weighted and traction environment.

Many studies of astronaut performance are conducted in a 1 "g" environment. An example of this simulation technique is seen in reports generated from the NASA Space center, Houston, Texas. LaFevers and Mason (1965) investigated the ability of subjects to perform lunar scientific tasks while wearing pressure suits. They concluded that after considering the constraints of wearing a pressure suit in a 1 "g" environment, and the nature of the terrain in which the study was conducted, performance of the four subjects was better than expected. More specific results indicated the 1 "g" simulation technique is not desirable when actions involving delicate finger manipulation near ground level is to be studied. It was further discovered that individual preference existed as to the usefulness of performance aids. Generally, however, the subjects did agree that the Jacob's staff was useful in traversing the more rugged terrain in addition to being a convenient carrier for geologic tools. Consensus of the subjects was that both Jacob's staff and the lunar-walker were useful devices.

This simulation was conducted in the Bend, Oregon area which has topography and volcanic surface material somewhat resembling that expected of the lunar surface. The procedure followed in conducting such investigations is to dress the astronaut in his life-support system and evaluate his performance in completion of various tasks. This method has been used in the evaluation of many hand tools, equipment packages, and general procedural sequences.

The obvious inadequacies of this methodology is the total lack of fidelity in all simulation parameters other than surface texture. Such factors as reduced gravity, lighting, ambient temperature, etc., have been excluded.

In December of 1966, K. V. Edmonds coordinated a field test of tools and geologic methods. Equipped with prototype Apollo tools and wearing a pressurized space suit, the test subjects were found to spend their time in the following manner:

1.	Geologic description	33%
2.	Photography	8%
3.	Sampling	19%
4.	Walking	22%
5.	Other	18%

It was concluded that astronauts in the lunar environment can adequately perform geological traverses in the limited time alloted during early missions.

While little simulation of lunar topography has been conducted, Jon Dornbach (1966)described briefly two simulation facilities that were planned at that time. One was a 625 sq. ft. indoor model which duplicates lunar surface albedo and lighting under various phases of earthshine. This model is located at Ellington AFB. Construction has just been started on the second simulation at site One. This will be an outdoor scaled model of 100 meter diameter, simulating lunar surface topography and geology. Studies will be made here of pressure suit mobility, mission time and motion studies with a LM mock-up, astronaut scientific mission training, etc. Moon topography has been constructed and based on a reduced scale factor of today's state of knowledge. Lunar geology has been superimposed upon this topography according to the photo-geological categories developed by the U. S. Geological Survey, Branch of Astro-geology. Plans have been made to continually update this surface with each new addition of data from the Ranger, Surveyor, and Orbiter programs.

As recently as April of 1968, Donald Lehr concluded in his NASA report Operational Hardware and Procedures Simulation for Apollo Lunar Surface Experiments Package (ALSEP): "the test location did not have an accurate surface or lighting simulation. Judgments as to the accuracy of the metabolic load on the crew member in this type test cannot be made. It should be pointed out that the facilities to provide high fidelity do not exist today. It is important that facilities which have these characteristics be developed. They will be invaluable for both crew operations equipment evaluation and training."

It can been seen that from the beginning of 1/6th "g" simulations to the present time, complete fidelity has not been achieved. This has been noted for those tests of locomotion and operational performance of hardware that have been conducted to date.

4.2.3 Energy Expenditures

NASA report CR-216 (April 1965) "Study of the Thermal Process for Man-In-Space" has the concluding statement that the metabolic energy expenditure on the moon will be less than on the earth. This conclusion is based on interpretations of Magaria and Cavgna's 1964 study of the mechanism involved in subgravity locomotion by humans. These experimenters found that walking at 1 "g" is obtained by alternating conversion of potential energy levels essentially out of phase. In running, kinetic and potential energy changes will substantially be reduced for locomotion in subgravity.

The authors of this NASA document do admit that much of the work in this field is sheer conjecture at the present time. They state "it can be hypothesized that increased muscular activity will be required to provide restoring forces for the body movement in reduced traction environments. That is, it will be necessary to use muscular forces to provide restoring effects normally provided by gravity or friction. On the other hand, however, it can also be postulated that less work will be required in a weightless environment, since the body will not be working against a gravitational field, in order to maintain a standing position for example." Due to the existence of contradictory hypotheses, they admit that the effect of reduced gravity on metabolic rate is somewhat uncertain at the present time.

Further evidence to substantiate both hypotheses is presented below. Lomonaco's research is cited to support the increased metabolic cost hypotheses. He reported an increase in metabolic rate of 34% for subjects walking on a treadmill. These subjects were dressed in light clothing and were performing in reduced gravity conditions ranging from ½ to 1/20 "g". Increases less marked were reported by Steimer, et al. These investigators observed a 12-15% increase in metabolic rates when their subjects performed arm extension/flexion cycling in a reduced gravity environment. Their subjects were in shirt-sleeves and pressure suited environments. In order to perform the task, one arm was used to do the work, while the other arm was used to provide a counteracting force to maintain their position. This was necessary because of the low traction environment. Other American and Russian studies are cited which indicate reductions in metabolic cost of between 28% to 48%.

Roth reported an increase in oxygen consumption of 34% for locomotion in reduced gravity over that found in earth gravity. He explains this increase by describing the gait patterns under reduced gravity and assuming that excessive limb movements lend to increased energy expenditure. The extra arm motions and the leaping gait are assumed to impose a severe metabolic burden. The use of new muscle patterns in a task would also decrease the energy efficiency of locomotion. As stated by this investigator, the total energy expenditure for walking a given distance on the moon may be greater than that predicted from a simple elimination of the energy requirement for the vertical component of the gait. It would appear that the 1/6 "g" environment of the moon may actually increase by some factor less than 34% the basic metabolic burden of locomotion rather than decrease it. This burden can be relieved significantly by training (Roth, 1966).

Findings reported by Litton Systems indicate a growing body of opinion that the effect of subnormal gravity environments is to increase the metabolic cost of performing work. It is assumed that this penalty is extracted by the necessity to bring into play muscle groups that are not ordinarily used.

Webb and Annis (1967) noted that extravehicular activity (EVA) in the weightless environment has an extremely high metabolic cost as evideneced by the sustained high heart rates of the Russian Cosmonaut and the American Astronauts.

Kuehnegger, Roth, and Thiede (1965) indicate findings that would also support the reduced metabolic cost hypothesis.

The use of inductive analytic methodology has also been employed by various researchers. H. J. Ralston and L. Lukin, (April, 1968) have attempted to use such a method and correlate their results with the works of other investigators who have used the inclined plane and the treadmill for estimations of the effects of gravitational and inertial work in the energy cost of human locomotion.

Inherent in their methodology were the concepts that loading of the body increases the metabolic cost of walking, but the effects are very dependent upon the nature of the loading. Loads placed upon the distal segments, especially the foot, have relatively much greater effect than loads attached to the trunk, due to the large inertial effects associated with acceleration and deceleration of the limb segments. They conclude that the initial effects of limb-loading on metabolic costs of walking may be expected to be critically important whether under 1 "g" or 1/6 "g" conditions, while the effects of trunk loading are relatively modest, even under 1 "g" conditions.

Specifications of research methodology were sorely wanting in this report. The authors did note that the inclusion of effects such as walking on soft terrain, irregular terrain, were not included in this report. They do speculate, however, that the compounding of restraint at joints, produced by either a soft or hard space suit, with difficult terrain, may be expected to have a very significant effect on the metabolic demand of walking. They do feel that more studies should be initiated to investigate this phenomenon more fully.

The question as to metabolic costs in various gravitational environments remains questionable even at this time. Robertson and Wortz (1968) initially believed that the energy cost of locomotion would be lower in reduced gravity simulations, and the results of their study confirmed this finding. While they were interested in evaluating various pressure suits, one of the significant results of their experiments was that "metabolic rates for walking are significantly lower in the 1/6 "g" environment than in the 1 "g" environment". It is of interest to note that the researchers did notice that the simulation technique did effect their results, although the above mentioned finding was valid for both simulation techniques. They discovered that metabolic rates were "significantly lower in the 6 degrees of freedom gimbal than in the inclined plane simulator".

Ralston and Lukin (1968) (NASA CR-1042), while investigating parameters interacting to effect the amount of energy cost of human locomotion, indicated that the "effect of reducing the gravitational work of walking by the factor 6 would result in a metabolic demand scarcely greater than that of quiet standing at the surface of the earth. Unfortunately, however, the effects of restraint by either a soft or hard suit are to nullify this advantage". (page 5)

Equating the suited astronaut on the moon and the shirt-sleeved man on earth, the above statement indicates that surface topography becomes an important determinant in man's locomotive capabilities. The same study quotes Passmore and Durnin who state: "the type of surface may have a slight effect on the energy cost of walking. However, unless the surface is markedly rough, the effect will probably not exceed 10% more than walking on a flat surface". In their analysis of this statement, Ralston and Lukin indicated an increase of about 35% in energy expenditure for a subject walking at a speed of 90 meters per minute on a ploughed field compared with an asphalt road. In the same vein they cite Strydon et al., who in a recent study of 11 young men found that "the metabolic cost of walking at about 80 meters per minute with loads of about 23 kg was 80% greater on loose sand than on a hard surface". (p. 7)

The results of various studies indicate that the lunar topography will degrade astronaut performance. Visual performance will suffer through the loss of cues enhanced by dispersion, reflection and a higher albedo level found on earth. Motor performance will suffer because of the increased expenditure of energy needed to perform certain tasks. This expenditure becomes even greater when segments of the astronaut's body are restricted or loaded such as by wearing a spacesuit, or when carrying objects.

Hewes (1967 b) concluded that energy expenditures can be related to stepping rates and that energy costs of lunar self-locomotion will be markedly less than those related to demands on earth. Russian studies have postulated a 30% decrease in the metabolic rate for walking on the lunar surface. Strughold

(1962) noted that since lunar gravity is about 17% that of earth, it will influence the metabolic rate in the direction of decreased metabolic turnover.

Hazard (1965) using the inclined plane reported that walking in lunar gravity conditions reduces the heart rate by 15 to 20 beats per minute. It was also reported that the average caloric expenditure in the lunar environment is 52% less than for earth gravity conditions. Using counterweight simulation, Wortz and Prescott (1965) and Sandban and Wortz (1967) reported that the energy cost associated with walking is less in 1/6 "g" than it is in 1 "g".

It is, therefore, unclear as to the precise effect of lunar gravity and topology on energy expended in locomotion activities. Evidence for increased and decreased metabolic rates associated with walking on the moon has been reported.

4.2.4 Psycho-Motor Capabilities

Most of the research on effects of lunar gravity on astronaut performance has been concerned with whole body motions such as walking, jumping, running, etc. Very little attention has been paid to the effects of 1/6 gravity conditions on psycho-motor performance. One study reporting effects of lunar gravity on performance of basic maintenance tasks (Shavelson and Seminara, 1967) indicated that for the tasks studied, lunar gravity imposed a 25% performance decrement over performance in 1 "g". The tasks studied included bolt torquing, connector mating, and nut threading. The performance decrement comprised an increase in time to perform. It was also reported that the torquing task required significantly more time to perform than the other two tasks.

Similar results were reported by Holmes (1965). This investigation attempted to establish the effectiveness of tools for maintenance tasks and found that performance times increased by eight percent in 1/6 "g" over times recorded in the earth gravity condition.

An important finding of studies relating to man's performance in 1/6 "g" should be noted. This is the fact that the suits used while conducting the studies degraded the operator's performance. The Lockheed studies (Shavelson & Seminara, 1967) did indicate that performance time increased in the 1/6 "g" condition, regardless of the mode of attire. However, additional degradation of performance was associated with the Apollo A-4H suit. The Lockheed study group felt that performance increases such as those reported in this research would be less with more advanced suits such as the Apollo A-6L suit or the Litton hard suit.

4.2.5 <u>Physiological Factors</u>

Bodily functioning under reduced gravitational fields might become disrupted to the point of effecting the astronauts performance. Gaume and Kuehnegger (N62-14504) believe that bodily systems that might be affected include the bones, muscles, heart and blood vessels, stomach, intestines, kidneys, and the bladder.

In their review of the literature, they state:

> We know from available medical data that in the two experimental environments mentioned (water suspension and bed rest), certain physiological changes occur with regard to bone and muscle structure, cardiovascular response to stress, gastrointestinal function, and renal function. Bones demineralize (negative mineral balance) and muscles atrophy, producing a negative nitrogen balance. Both minerals and nitrogen, as they are removed from the tissues, are excreted through the kidneys. In prolonged bed rest, these changes in bone and muscle are considerable even in healthy young subjects and are evident both in X-rays and in the functional ability of the tissues. Kidney stones often form as a result of the increases calcium and mineral content of the urine and a change in ph toward the alkaline side, which favors the percipitation of mineral salts and stone formation.
>
> Lunar gravity should be sufficient for adequate bladder function, although the question arises as to how completely the bladder can be emptied in weightlessness and in sub-gravity states of low order. Incomplete emptying promotes urinary tract infections under normal gravity conditions.
>
> Cardiovascular and gastrointestinal dynamic functions are not likely to deteriorate as rapidly on the moon as in a state of weightlessness, but these functions would deteriorate without adequate, properly directed physical activity." (p. 8-10)

Many of the adverse effects found in a 0 gravity condition will not exist. The sensory receptors of the body such as the vestibular organ and the abdominal viscera will receive the stimulation missing in free space flight. With this stimulation problems of disorientation and nausea should be reduced. It should be noted that the Russian astronaut, Titov, was most adversely affected by his space flight while none of the United States astronauts have experienced this discomforture. One of the hypotheses for this difference is the lack of normal flight experience the Russian had been exposed to. It appears logical that astronaut pilots such as the men we have used might be more accustomed to unusual gravity environments such as those found in flight. This might assist their performance in the Lunar environment.

In an investigation conducted at Grumman Aircraft Engineering Corporation (1967), in which two subjects participated, the 1 "g" environment with the A-4H pressure suit was used. The study was interested in the physiological demands of certain tasks and performance times for completion of these tasks. The tasks studied were those anticipated in long-term lunar missions involving a LM shelter and LSSM.

The results of this investigation supported findings reported by Williams (1965), who documented gross physiological deviations in various organs and internal systems, for human beings. The Grumman report shows energy expenditure differences of more than 50% between the two subjects used in the testing situation. This finding can have great significance for future research. It sheds some light on the questions of sample sizes. As Williams has reported, differences by a factor of 7 have been reported for individuals in terms of heart volume, pumping capacity, etc. Similar findings have been reported in terms of lung capacity and other internal structures for "normal" individuals. These factors will affect an individual's capabilities to perform various segments of the different missions anticipated in lunar exploration.

Because of the differing reports from various experimenters, and because of the large physiological differences found in "normal" subjects, it is believed that a greater body of information involving larger population sizes is needed prior to extrapolation to astronaut locomotive ability and metabolic cost of this activity on the lunar surface.

When studying the effects of a reduced gravity environmental on man's phsiology, the two principle methods of simulation are water immersion and bed rest. Many of the findings of these simulation techniques have been verified by studies of American and Russian astronauts after their orbital flights.

Charles A. Berry (1968) noted that many factors obtained from in-flight recordings of the Mercury and Gemini programs have been extrapolated to astronaut functioning on the moon. In some respects the simulation of zero gravity in these conditions is ideal since the astronaut has been placed in a zero gravity environment for up to 14 days. These flights indicate that significant physiological changes were appearing in the astronauts and that these changes were similar to the ones found during prolonged bed rest or water immersion simulation studies.

Prior to such verification, Gaume and Kuehnegger (1962) reviewed the effects of chronic lunar gravity on human physiology.

They stated that "water suspension does not produce true weightlessness, but it does remove the weight of the body from the skeletal structure and obviates the need of using the anti-gravity muscles to hold the body erect. Since muscles are not required for support, there is a loss of beneficial muscle action on the vascular system situated with those muscles and, therefore, there is a change in the pattern of blood circulation, which is reflected in the behavior of the heart itself. There are changes in rate, stroke volume, and eventually in the strength of the mycardium itself. This in turn affects the oxygen-carrying capacity of the blood, as well as the ability of the cardiovascular system to respond to a sudden physical stress such as the sudden application of a total body gravity load or a sudden heat stress.

Lunar gravity, being one-sixth of the gravitational force to which man is normally accustomed, will provide some unique experiences for the individual exposed to this new sub-gravity state. Man will have to adjust himself to the fact that he will only have to support 1/6th of his earth weight, and while his load carrying potential will remain the same as one earth, he will be able to support six times the loads under this state. In this extrapolation, it is believed that the authors did not consider the possibility that if decalcification of bone does take place in the lunar environment, the astronauts skeletal structure might not be able to support this proportionally greater load.

Letko, Spady, and Hewes (1966) reported that the semicircular canal function will be similar in the lunar environment as on earth. They do believe, however, that otolith organ functioning and the functioning of the proprioceptive mechanisms will be affected. This conclusion is based on tilt test results using a padded chair/water immersion studies which indicated that the subjects tended to show a decrease in their accuracy to indicate the vertical.

Other areas of investigation concerning the physiology of man in reduced gravity environments were discussed by Swan (1968). He concluded that while cardiovascular deconditioning and mineral metabolism imbalances were the most prominent areas of concern, the research into atmospheres used in space exploration must continue. An example of this research was an investigation conducted by McDonnell Douglas Company, in which human subjects were placed in a 68% oxygen and 32% nitrogen environment for 60 days. This environment was controlled at 258 mm Hg. At the end of the 60-day testing period, the subjects were evaluated for physiologic impairment. No detectable impairment had occurred. This experiment validated the oxygen-nitrogen environment as causing no detectable physiological damage, whereas studies of a pure oxygen environment at the same pressure levels had been known to cause reversible changes in the red blood cell mass of the human subjects.

Medical studies are also being conducted to evaluate the effects of various diets upon human subjects. Dr. John E. Vanderveen (1968) reports of studies conducted at the Physiology Branch, Environmental Physiology Division, USAF School of Aerospace Medicine, Brooks AFB, Texas. These studies have used bed-rest simulations extensively. While this method more nearly represents a zero "g" condition, the results have been extrapolated to the lunar program.

The results of these investigations indicate that lean body-weight measurements are reliable in estimating human caloric requirements. It is believed that 41 kilocalories per kilogram per day of lean body weight is sufficient to maintain body weights for periods of up to at least 60 days.

It is believed that these results must be used with caution and probably represent low estimations, since the subjects were in zero gravity and under no physical stress. This is not the condition the astronaut will encounter on the moon.

Another study of this nature was conducted by Katchman, et al., (1967). His four subjects participated in a six-week study to determine the water, caloric, and protein requirements of individuals encountering simulated aerospace stress. A summary of his method and results are as follows:

"The subjects spent 28 days in the life support evaluator; 2 subjects wore the MA-10 space suit, unpressurized for 8 hours per day, fresh food diet and a 1-cycle, 4 meals per day, liquid food diet. The only variety in the fresh food diet was in the meat and fruit served at each meal. This diet was highly acceptable and did not show monotony even after 21 days. The only variety in the liquid food diet was the four flavors -- cherry, vanilla, chocolate, and strawberry. This diet was unacceptable and was monotonous; it became less acceptable with time. The fresh food diet was comprised of 81 g of protein, 164 g of fat, 166 g of carbohydrate, and 2,329 kcal of energy. The liquid diet was comprised of 79 g of protein, 167 g of fat, 204 g of carbohydrate, and 2,444 kcal of energy. The daily requirement of water was about 3,300 ml while on the fresh food diet and about 2,500 ml while on the liquid food diet. The liquid food diet was utilized less efficiently than the fresh food diet. As a consequence, the subjects were in negative balance for calcium, potassium, and phosphorus although the concentrations of these elements in the diet were many times that found in the fresh food diet. The caloric value of the diet would support only a 65 kg man without weight loss. All the clinical data including heart rate, blood pressure, and oral temperature were in the normal range and no significant differences were observed due to confinement in the Life Support Systems Evaluator or due to wearing the MA-10 space suit, unpressurized.

4.2.6 Spatial Orientation

The body system which is responsible for sensing body movements and body position is the proprioceptive system. Receptors of this system, or proprioceptors, are of two kinds - kinesthetic and vestibular receptors. Both are stimulated by movements we make or bodily positions we assume.

Kinesthesis, according to Jenkins (1951), is probably the most important sensitivity man possesses. Without it, a person cannot maintain erect posture, walk, talk, and engage in other skilled activities. In kinesthesis at least three different kinds of receptors are involved - nerve endings associated with muscles, tendons, and joints. Muscle endings are stimulated by the stretching of the muscle, tendon endings are stimulated when muscles contract, and joint endings are stimulated when joints are utilized. These receptors give knowledge of position as well as movement.

Vestibular receptors are found in the labyrinth of the inner ear. The vestibular apparatus consists of three semicircular canals and the otolith organs (utricles and saccules). The canals are used to detect movements of the head and are the chief receptors for rotational movement being affected by angular accelerations. The otolith organs respond to gravity and to linear accelerations. They control static reflexes to position of the head and dynamic reflexes in response to movements.

In a study of the localization of the visual horizon, Clark and Graybiel (1967) used normal and labyrinth defective observers and different combinations of head and body tilt. Their results indicated that vestibular information is not required for veridical perception of the visual horizon. As indicated by Letko et al. (1966) little data exist on the effects of reduced otolith stimulation (as to be expected in the lunar environment) on equilibrium. Otolith thresholds range from 3.4×10^{-4} to 10^{-2} "g"; however, these values must be maintained for a period of time in order to be perceptible. The minimum values of acceleration for maintaining undegraded postural equilibrium have not yet been established. These investigators conclude that otolith organs and kinesthetic receptors will be directly affected by reduced gravity. With reduced stimulation of these organs and in the absence of vision man may have difficulty in judging the vertical (Letko et al., 1966).

A study of the capability of man to perceive the visual vertical under reduced gravity conditions was conducted by Hammer (1962). Using four levels of gravity (1g, .5g, .25g, and 0g) obtained in parabolic flight, this experimenter reported that errors in judgments of the vertical in an unstructured field increased as gravity decreased. It was noted, however, that due to the size of the decrement over the gravity range (2 degrees), it cannot be stated that other sensations did not enter into the perception, or even that stimulation of the gravity receptors was the most important of these sensations. A threshold for perception of gravity influences the subjective verticle at some point between .5 and .25 "g" (Hammer, 1962).

Noting that Russian Cosmonauts have experienced orientation disturbances of probable vestibular origin, Miller et al. (1965), studied the ocular counter-rolling response on normal and bi-laterally labyrinthine defective subjects. The gravity conditions studies were 1 "g", ½ "g" and 0 "g". The results indicated that the magnitude of the counter-rolling at .5 "g" was less then expected in terms of the magnitudes associated with the 1 "g" and 0 "g" conditions.

Gaume and Kuehnegger (1962) postulated that the vestibular organs would be sufficiently stimulated in the lunar gravity environment so as to avoid disorientation, nausea, and similar reactions.

4.2.7 Radiation Safety

As described by Richmond et al. (1968), the complex nature of Apoll Lunar Missions infers greater uncertainty in radiation exposures. Once the spacecraft leaves the protection of the magnetic field of earth, it is vulnerable to energetic particles accelerated by solar flares. These solar particle events vary widely in their frequency of occurrence, intensity, and spectra. Since this radiation environment can be significant in terms of crew safety and mission success, an operational dosimetry system with active and passive elements has been developed for Apollo. Active systems include a alpha-proton spectrometer, skin and depth-dose rate dosimeters, personal integrating dosimeters, and a portable hand-held radiation survey meter. Passive dosimetry systems consist of several layers of nuclear emulsions and films packaged with a lithium thermoluminescent powder.

There are two basic kinds of space radiation; particle radiation and electro-magnetic radiation. Particle radiation includes the protons, neutrons, electrons, atomic nuclei stripped of orbital electrons, and the smaller particles such as meaons, pi meaons, etc. The electromagnetic radiation refers primarily to X and gamma rays. The energy of any kind of radiation can be expressed in MEV (million electron volts).

Radiation penetrates matter and, in the interaction with matter, cause pairs of positive and negative ions to be formed along the path of the incident particle or photon by loss or gain of an electron. For this reason, the term ionizing is something used to refer to space radiation. The less energetic radiations may penetrate only a fraction of a millimeter, while the more energetic can penetrate many inches of lead. Penetration implies entry to at least 10 microns, which is slightly beyond one cell layer. The absorption of radiation in matter involves the transfer of all or some portion of the incident radiation energy to an electron or nucleas in the absorber mass. This may lead to the production of recoil protons, electrons, X and gamma radiation, or many other secondary particles. The space radiations are not qualitatively different from coventional radiations in this regard, but quantitatively the production of secondary radiation is somewhat unique. This is due to the presence of particles of unusually high energies that can generate a cascade of secondary photons and particles. The exact nature of the secondaries will be a function of the incident particle and its charge and energy, the density of the absorbing or shielding material and its thickness, and the proximity of masses of different composition or elemental form (laminated shielding, capsule wall, and black boxes). In other words, while shielding is certainly an effective countermeasure, it does modify the quality of the radiation, which must then be the radiation of interest for biological consideration.

The space radiation sources of concern to the Apollo Mission are the following three: the primary or galactic cosmic rays, the geomagnetically trapped radiation (Van Allen belts) and the solar flare events. Except for the solar event, radiation levels are fairly well known and they are relatively constant. Since the levels are known and constant, the proper type and amount of shielding has been calculated and included into the Apollo design.

As described by Hekhuis (1962), cosmic radiation of galactic origin is omni-directional as observed from earth. The intensity measured on the earth varies but this variation exhibits a regular periodicity of about eleven (11) years, which is considered to be the effect of the magnetic activity of the sun-environment associated with its approximate eleven (11) year sun spot cycle. Culver (1962) reported that it is agreed that galactic cosmic radiation can neither be shielded against completely nor avoided. Due to the low probability of a sufficient number of hits from the heavy particles the dose on an erg per gram basis would appear to be less than the AEC tolerance limit and should, therefore, pose no problems in the general sense. Long-term biological effects from single bits of such particles have not been adequately investigated.

Solar flares are large chronospheric eruptions on the surface of the sun which may best be observed by the light of the hydrogen alpha line with a spectro-helioscope. There is a 10 to 20 minute delay after the appearance of a visible solar flare and the arrival of particles in the region of the earth.

Unfortunately, as of now, solar cosmic ray events cannot be predicted in advance with high reliability. Some general periodicity has been observed in solar events. However, the minimum period was in 1965 and it is expected that the next cycle will peak in the 1969-70 period, although it probably will be considerably less than the last peak in 1958. Of course, the dose load of most solar cosmic ray events is less than required to cause any serious long or short-term biological effects. But because the dose varies by many orders of magnitude for solar cosmic ray events, it is not possible to construct an "average event" or predict the "average dose". Consequently, the levels and dosages must be monitored, analyzed and considered as the mission progresses so that undesirable radiation dosage levels are prevented from occurring.

The characteristic biological effects of radiation are relevant to mission decision framework and criteria and should, therefore, be considered in the determination of the radiobiological circumstance to continue or discontinue the mission. These data have been assembled from several sources which show some variation but in general, there is agreement between them. In the determination of radiobiological circumstance, many factors must be considered. Among these factors are, the type of radiation (e.g., X or gamma), amount of dose, time duration of exposure at given rate, whether the radiation is of high or low energy, and the amount of body exposure and dose at depth. Associated with all of these factors are physiological effects of radiation which vary according to the amount, type, and duration of radiation. There are several parameters of radiation which must be utilized in the determination of the radiobiological circumstance. The amount of radiation present outside or inside the vehicle is only indirectly related to the damage which will be caused to the crew. This is because the amount of dosage varies by a number of factors such as amount and type of secondary radiation produced, the angle of incidence of the radiation, the exact nature of the radiation, etc. Consequently, only the amount of radiation actually absorbed by the man is of interest. This is determined by the dosimeter which measures the amount of radiation which has actually penetrated a simulated skin material to some proper level.

This amount or dose of radiation absorbed (any kind of radiation), is measured in terms of the rad (radiation absorbed dose). However, there is not a direct relationship between the rad dosage and the biological reaction because each type of radiation produces different amounts or degrees of damage (compare Figure 9 and 10). The LET (linear energy transfer) meter is a device which determines the kind of radiation which is being received. With this information a constant RBE (relative biological effectiveness) factor for each type of radiation can be used to convert the rad figure to rems (roentgen equivalent per man) (See Table 24). The rem is the amount of radiation (as adjusted by radiation type) which causes some tissue damage or change in man. (The exact definitions of these terms are presented in Table 25.) With a measure of rads and LET, the rem dose can be computed by utilizing the LET to determine the specific type of radiation and its rbe (relative biological effectiveness) factor. By multiplying the rad and rbe, the rem dose is obtained and used to determine the radiobiological status of the crew.

Since the validity of the radiation data is important, for obvious reasons, some means of assuring the proper functioning of the active dosimeter should be determined. Also the passive dosimeters to be worn by the crew should be periodically checked

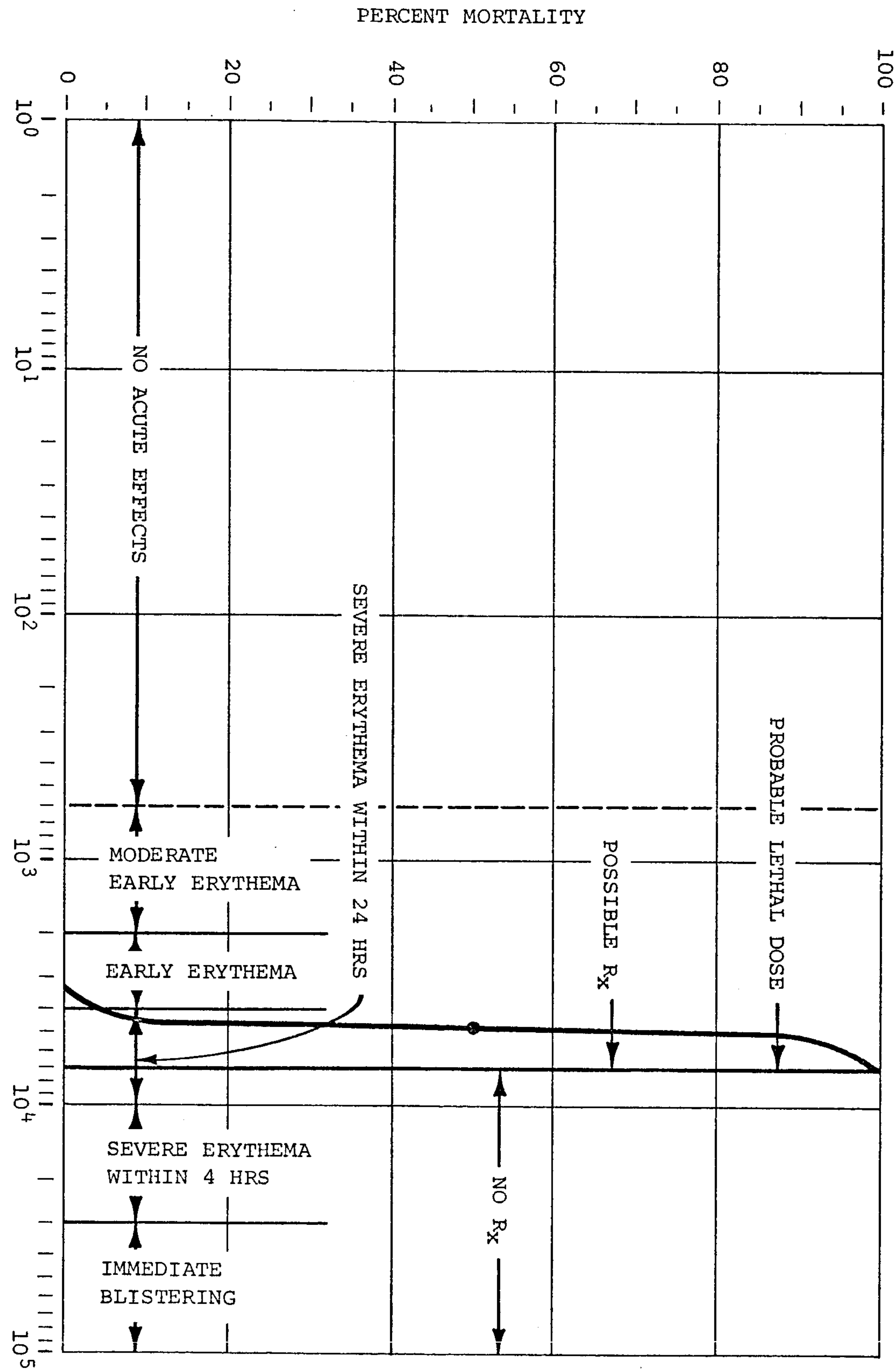

FIGURE 9. RADIATION DOSE (RADS)

LOW ENERGY RADIATION

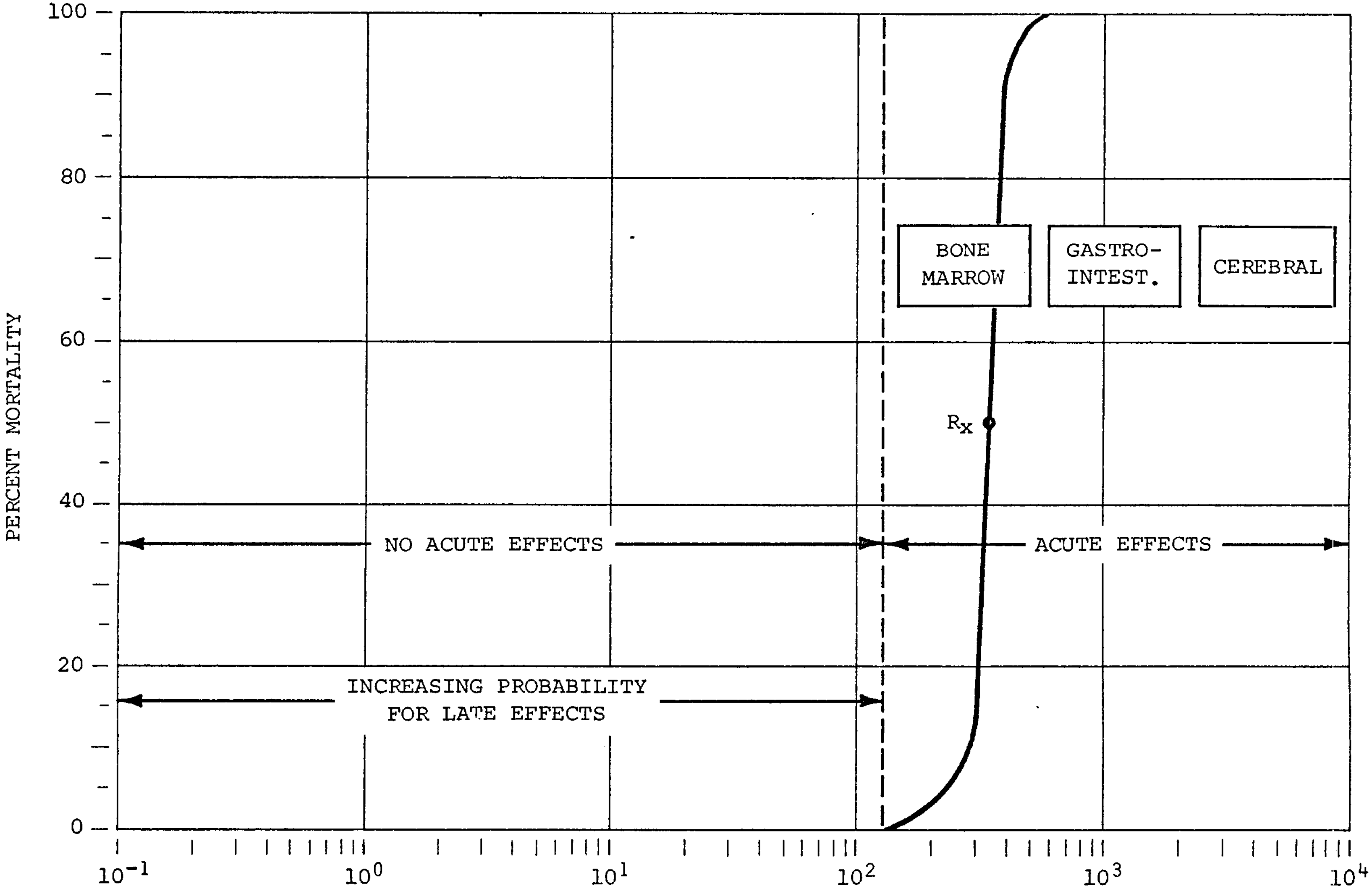

FIGURE 10. RADIATION DOSE (RADS)
PENETRATING RADIATION

TABLE 24.

CONVERSION: RAD TO REM

Based on most determental chronic biological effects for continuous low dose exposures.

TYPE OF RADIATION	RBE
X rays	1
Gamma rays	1
Beta particles, 1.0 mev	1
Beta particles, 0.1 mev	1.08
Neutrons, thermal	2.8
Neutrons, 0.001 mev	2.2
Neutrons, 0.005 mev	2.4
Neutrons, 0.02 mev	5
Neutrons, 0.5 mev	10.2
Neutrons, 1.0 mev	10.5
Neutrons, 10 mev	6.4
Protons, 100 mev	1.2
Protons, 1 mev	8.5
Protons, 0.1 mev	10
Alpha particles, 5 mev	15
Alpha particles, 1 mev	20

TABLE 25.

RADIATION TERMS

One r (roentgen) is the quantity of gamma or X-radiation that produces an energy absorption of 83 ergs per gram of dry air.

One rep (roentgen equivalent--physical) is the quantity of radiation that produces an energy absorption of 93 ergs/gm of aqueous tissue.

One rad (radiation absorbed dose) is required to deposite 100 ergs/gm in any material by any kind of radiation.

One rem (roentgen equivalent--per man) is the unit of particulate radiation that produces tissue damage in man.

The conversion factor from rad to rem is the "relative biological effectiveness," i.e., dose in rem = dose in rad x rbe. Esample for total dose: for a given exposure time, a dose of 0.2 rad of gamma radiation, plus 0.04 rad of thermal neutrons, gives a total dose of (0.2 x 1 rbe) + (0.04 x 2.8 rbe) = 0.312 rem.

against the active dosimeter(s) in order to provide verbal correction via voice communication of the radiation data. Discrepancies in the data may occur due to the differences in location of the active dosimeter and the crew members.

The amount of rems which a crewman can sustain is a function of time (see Table 26 and Figure 11). This is because the body can repair the effects of damage by radiation, but only if the damage done at any one time, does not exceed a certain point (see Tables 27, 28, and 29). If the radiation dosage rate is greater than the body's tissue repair rate then the effects are accummulative.

Dosimeter and LET meter outputs should be continuously recorded while on the lunar surface with time indexing. Data received at mission control should be recorded and analyzed by computers. The same dosimeter data can be processed in a number of ways; to yield rad dose, rem dose, or the dose which contributes to a specific effect such as cataract production, etc. In fact, the output from a single exposure of the dosimeter can be used to determine the dose received for a given exposure as related to any number of different effects.

Basically, a running accumulated total dosage of radiation in rems received by each crewman should be maintained. This will serve as a baseline for other calculations as well as information when the accumulation dosage has or will (if the accumulation continues at the same rate) reach a level requiring some

TABLE 26.

EXPECTED EFFECTS FROM ACUTE WHOLE-BODY RADIATION

DOSE IN RADS	PROBABLE EFFECT
0-50	No obvious effects, except possibly minor blood changes.
50-100	Vomiting and nausea for about one day in 5 to 10% of exposed personnel. Fatigue, but no serious disability. Transient reduction in lymphocytes and neutrophils.
100-200	Vomiting and nausea for about day, followed by other symptoms of radiation sickness in about 25 to 50% of personnel. No deaths anticipated. A reduction of approximately 50% in lymphocytes and neutrophils will occur.
200-350	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness, e.g., loss of appetite, diarr minor hemorrhage. About 20% deaths within 2 to 6 weeks after exposure; survivors convalescent for about 3 months.
350-550	Vomiting and nausea in most personnel on first day, followed by other symptoms of radiation sickness, e.g., fever, hemorrhage, diarrhea, emaciation. About 50% deaths within 1 month; survivors convalescent for about 6 months.
550-750	Vomiting and nausea, or at least nausea, in all personnel within 4 hrs. from exposure, followed by severe symptoms of radiation sickness, as above. Up to 100% deaths; few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1 to 2 hrs. Probably no survivors from radiation sickness.
5000	Incapacitation almost immed. (several hrs). All personnel will be fatalities within 1 week.

ACUTE RADIATION ILLNESS

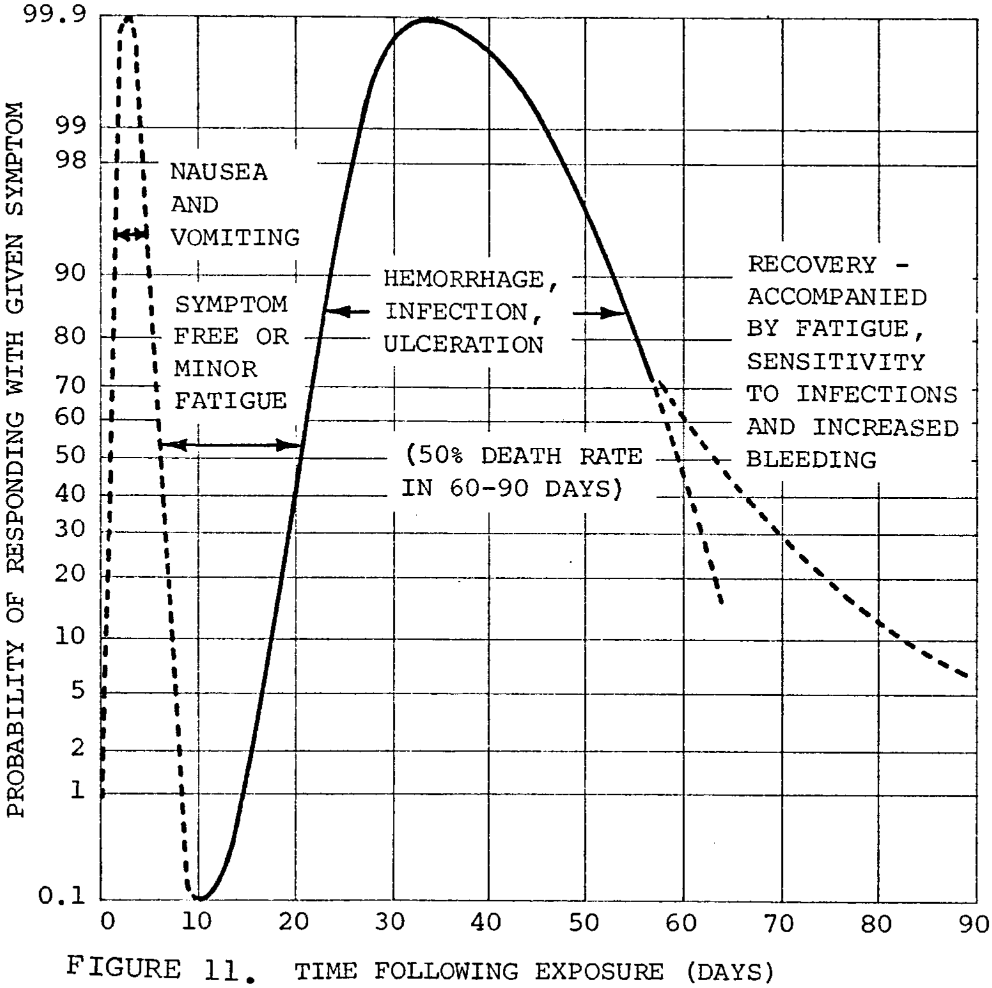

FIGURE 11.

TABLE 27.

EXPOSURE TOLERANCE VALUES FOR MAN

WHOLE-BODY RADIATION DOSES

0.001 rem/day	Natural background radiation
0.01 rem/day	Permissible dose range 1957
0.1 rem/day	Permissible dose range 1930-50
1 rem/day	Debilitation 3 to 6 months; death 3 to 6 years (projected from animal data)
100 rem	1 day--survivable emergency exposure
150 rem	1 week--dose but permitting no further
300 rem	1 month--exposure for life
24 rem	Single emergency exposure
100 rem	Twenty-year career allowance
500 rem	Maximum permissible twenty-year career allowance

TABLE 28.

RADIATION EXPOSURE DOSE LIMITS

Critical Organ	Maximum Permissible Integrated Dose (rem)	RBE (rem/rad)	Average Yearly Dose (rad)	Maximum Permissible Single Acute Emergency Exposure (rad)	Location Of Dose Point
Skin of whole body	1,630	1.4	233	500[1]	0.7-mm depth from surface of cylinder 2 at highest dose rate point
Blood-forming organs	271	1.0	54	200	5-cm depth from surface of cylinder 2
Feet, ankles, & hands	3,910	1.4	559	700[2]	0.07-mm depth from surface of cylinder 3 at highest dose point
Eyes	271	2[3]	27	100	3-mm depth from surface on cylinder 1 along eyeline

[1] Based on skin erythema level.

[2] Based on skin erythema level but these appendages believed to be less radiosensitive.

[3] Slight higher RBE assumed since eyes are believed more radiosensitive.

Rads may also be used to determine the radiobiological status of the crew, although rads do not give qualitative data. This table presents yearly rad doses which may be tolerated by man. As indicated under max permissible single acute emergency exposure (rad) 100 rads requires immediate protection for eye lenses, 200 rads requires immediate protection of blood-forming organs. Above these levels, unless body protection is provided, latent and long term effect are inevitable.

TABLE 29.

RECOMMENDED MAX WEEKLY DOSAGE REMS/WEEK

RADIATION	SKIN Total Body	SKIN Appendages	LENS OF EYE	GONADS	BLOOD FORMING ORGANS	INTERMEDIATE TISSUE (0.07-5.0 cm DEPTH
X or Y rays 3 MEV	0.45	1.5	0.45	0.3	0.4	0.4-0.45
Electrons or beta	0.6	1.5	0.3	0.3	0.3	0.3-0.6
Protons	0.6	1.5	0.3	0.3	0.3	0.3-0.6
Fast Neutrons	0.3-0.6	0.75-1.5	0.3	0.3	0.3	0.3-0.6
Thermal Neutrons	0.5	1.2	0.3	0.1	0.17	0.17-0.5
Alpha Particles (a)	1.5	1.5	0.3	0.3	0.3	0.3-1.5
Heavy Nuclei (O,N,C) (locally generated)	1.5	1.5	0.3	0.3	0.3	0.3-1.5

This table presents weekly rem dose rates for consideration; since these dosages are accumulative in nature a constant updating of radiobiological status is required. These tolerances are based on a weekly dosage rate and do not account for an acute dose (short-term, high intensity) rate. The acute dose tolerances indicate that 100 rem in 1 day is the survivable emergency exposure, and requires immediate remedial action.

corrective action to prevent further exposure. Also a rate of dosage accumulation must be calculated, as this figure is required in order to predict how long the current dosage can continue at a given rate before undesirable effects can be expected. In the event of solar flares, when larger fluxes of radiation can be expected for relatively short time periods, the dosage received for the event is compared with the radiation level limit for single doses (See Table 30). This limit must be constantly revised to reflect the current accumulated dosage. The limit should include a liberal margin of error to account for variations in the data accuracy and the individual differences in reaction to radiation.

4.2.8 Habitability

According to Fraser (1968) the term habitable refers to that equilibrium state resulting from the interactions among the components of a man-machine-environment-mission complex which permits man to maintain physiological homeostasis, adequate performance, and acceptable social relationships. On the basis of this interactive model, the attributes of habitability comprise the attributes of man and his relationships with other system components which influence the acceptability of the system to the man. Man is the basic reference criteria for human habitability and also a component of the system.

Celentano and Adams (1960) emphasize that habitability depends on the presence of desirable qualities to which the

TABLE 30.

USING THE COMBINED DATA FROM SEVERAL SOURCES, THE RADIOBIOLOGICAL CIRCUMSTANCE TO CONTINUE OR DISCONTINUE THE MISSION IS AS FOLLOWS:

REMS	100 rem--1 day; survivable emergency exposure abort mission
	25 rem--single emergency exposure abort mission
	$>$ 25 rem--10 rem--initiate corrective action
	$>$ 10 rem--1 rem--alarm, monitor system for possible corrective action
RADS	250 to 300 rads abort mission
	$>$ 250 to 100--alarm, monitor system for possible corrective action

Chronic doses are accumulative and must be monitored in order to determine when intolerable levels will be reached tenant is accustomed. Kubis (1965) stated that habitability is a global concept involving physical, physiological, psychological, and social components. The physical component describes the structure and form of the supporting environment; the physiological component relates to the homeostatic response of the individual within the environment; the psychological component comprises human behavior and performance capability; and the social component includes inter-personal relations.

In any lunar mission where a significant portion of the astronaut's time is spent inside a shelter, the habitability of that shelter becomes an important consideration. In defining habitability requirements, it is advisable to view the shelter and associated equipment as a habitability system with which the astronaut must interface at many levels. The system encloses, sustains, and supports the astronaut, sheltering him from the radiological and thermal environment of the moon, ensuring that basic body functions are served, that basic body needs are satisfied, and that performance of mission related operations does not degrade over-time.

The principal input to the lunar surface habitability system will comprise data describing representative missions, mission requirements, and mission constraints. Missions are described by the mission objectives and by the relationship of the shelter to the primary mission activities. Mission requirements include specifications of crew size, duration of the lunar stay, and descriptions of operations to be performed by the astronauts during the mission. Mission constraints include equipment constraints and environmental constraints. Equipment constraints encompass the characteristics of lunar vehicles, scientific equipment to be operated by astronauts, tools, mobility aids, illumination and sighting devices, etc. Environmental constraints include the characteristics of the pressure suit and associated equipment and their effect on astronaut mobility, field of view, and life support, and characteristics of the human environment which are known to affect human performance and/or biomedical status.

System outputs include the assurance of physiological homeostasis, adequate performance of mission related operations, and acceptable social relationships among crew members. Two general functions performed by the habitability system include: (1) providing support of life and mission activities and (2) providing for living functions and off-duty activities. The first function is related to station design to meet basic living-working requirements of the astronaut. These requirements include environmental control/life support (EC/LS) considerations, free volume requirements, station compartmentalization, allocation of available free volume to compartments, decor, illumination, and mission equipment layout and arrangement. The second function, that of providing for living functions and off-duty activities, includes the equipment design and arrangement for such human functions as:

- sleep
- nourishment
- waste elimination
- rest and relaxation
- exercise
- locomotion
- maintenance of personal hygiene
- equipment care and housekeeping
- medical - dental care

4.2.8.1 Shelter Configuration/Compartmentalization

Fraser (1968) recommended four distinct compartments for a station design, which include a work unit, a public unit, a personal unit, and a service unit. The Garrett (1964) recommendation for the Lunar Exploration Systems for Apollo (LESA) includes a living compartment, laboratory compartment, and airlock.

One feasible approach toward compartmentalization for a multi-man, long duration mission could require four separate areas: working area where mission-oriented operations and experiments are performed; sleep areas, either one sleep area for each crew member or some integration of areas for sharing of sleeping facilities; one area for rest, relaxation, medical care and exercise; and, one waste elimination area. A personal equipment area could conceivably be shared with the sleep area.

Constraints on compartmentalization concepts include needs for privacy, effects of isolation and confinement, needs for social interactions, needs for personal belongings, available volume, number of crewmen, duration of mission, work/rest cycles, activities requiring two or more crew members, pressurization requirements, and requirements for interfaces with the external environment.

Shelter configurations which have been proposed include a LM shelter, a fixed shelter, and a mobile laboratory/shelter (MOLAB).

a) <u>LM shelter</u>

For short duration missions some consideration has been given to utilizing the LM vehicle as a lunar shelter. This approach would require providing a shirt-sleeve environment, or at least a vented suit environment for one or both astronauts while they are within the LM and the inclusion of an airlock to enable one or both crewmen to access or egress the vehicle without requiring purging and repressurization. Problems associated with this approach stem primarily from the fact that the LM was designed as a flight vehicle with the objective of transporting men and/or material to the lunar surface, landing on the surface, and transporting astronauts back to the orbiting command module. The interior cabin of the vehicle is sized and arranged to support these flight functions. Provisions for supporting habitability functions such as sleeping must be included into the vehicle to enable it to operate as a shelter. Provisions for eating, drinking, and waste management are already being planned for the vehicle.

b) Fixed shelter

In the opinion of Branley (1963) and Drake (1962) lunar shelters will be buried below the surface of the moon. A sub-surface shelter has the advantages of being further shielded from meteoric dust and cosmic particle bombardment, and of reducing the requirements for regulating shelter interior temperature as a function of varying outer temperature. At a depth of 10 feet below the surface the lunar rock is estimated to have a constant temperature of -10 degrees F (Branley, 1963) or -40 degrees F (Drake,1962) regardless of the temperature of the surface.

The shelter would be spherical or hemispherical to ensure that the outside pressure is the same everywhere and to ensure maximum deflection of meteorites (Branley, 1963).

One of the more ambitious attempts to describe habitability requirements for a lunar shelter was the Garrett Airesearch Manufacturing Company's Lunar Exploration Systems for Apollo (LESA) human factors study (1964). A LESA module was proposed as comprising three separate compartments - a living area, laboratory, and air lock. A diagram of the LESA shelter layout is depicted in Figure 12. As crew sizes increased for lunar exploration missions, the number of modules to be employed

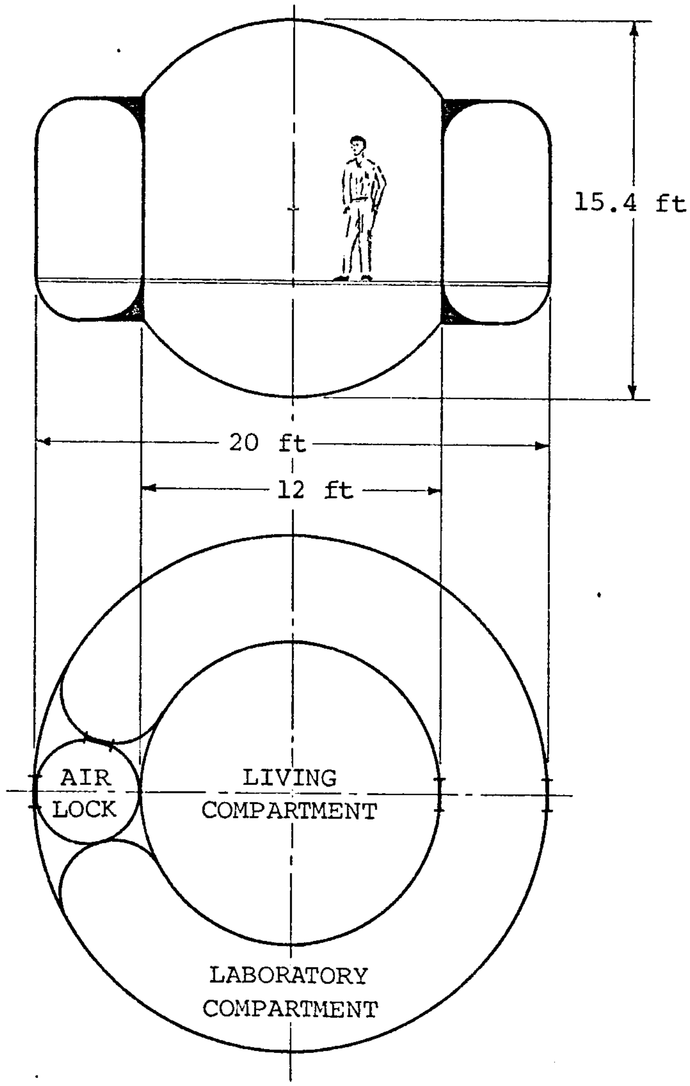

FIGURE 12. LESA MODULE LAYOUT

also increased. The gross volume and floor area for individual modules and the relationship of mission duration, crew size, and number of modules is presented in Table 31.

TABLE 31.

LESA VOLUMES, AREAS, AND NUMBER OF MODULES FOR DIFFERENT MISSIONS

	GROSS VOL. $Ft.^3$	FLOOR AREA $Ft.^2$
Living compartment	1421	113
Laboratory compartment	1875	161
Air lock	148	14

Atmospheric Leakage = 4.0 lb/day

LUNAR BASE CONCEPT	CREW	MISSION DURATION	NO. OF SHELTERS
NO. 1	3	3 months	1
NO. 2	6	6 months	1
NO. 3	12	1 year	2
NO. 4	18	2 years	3

c) Mobile shelters (MOLAB)

The Apollo Logistics Support System (ALSS) Lunar Mobile Laboratory (MOLAB) has been configured by Boeing to comprise a horizontal cylinder with 210 cubic feet of cabin volume, of which 200 cubic feet is free volume, and an air lock of 80 cubic feet. This vehicle is designed for two-man operation and includes provisions for driving about the surface, performing laboratory functions such as rock sample measurement, and living within the vehicle (Woods and Erlanson, 1966). The MOLAB developed by Bendix includes a separate chassis, cabin, and major components. The cabin includes 452 cubic feet volume and is covered with a fiberglass mat for thermal and meteoroid protection. A polyethylene sit-in storm cellar arrangement is provided for solar flare protection. The accomodations of the vehicle include a two-man forward driver-navigation station, emergency rear driving station, side scientific work station, sleeping provisions in the forward cabin and an air lock, two rear air lock accomodations, and a clear central aisle.

An attempt to evaluate the effects of an 18-day mission in a minimum volume MOLAB was reported by Haaland (1966). This simulation study has two subjects inhabit a cylindrical vehicle, Lunex II, of the following dimensions: main living space - 115.3 cubic feet, and air lock - 48 cubic feet (65.9 feet in the expanded emergency mode). While from thirty minutes to one hour per subject per day was spent in simulated lunar surface activities, ninety-six percent of each subject's time during the study was spent inside the vehicle in a shirt-sleeve environment. The dimensions of the vehicle are depicted in Figure 13.

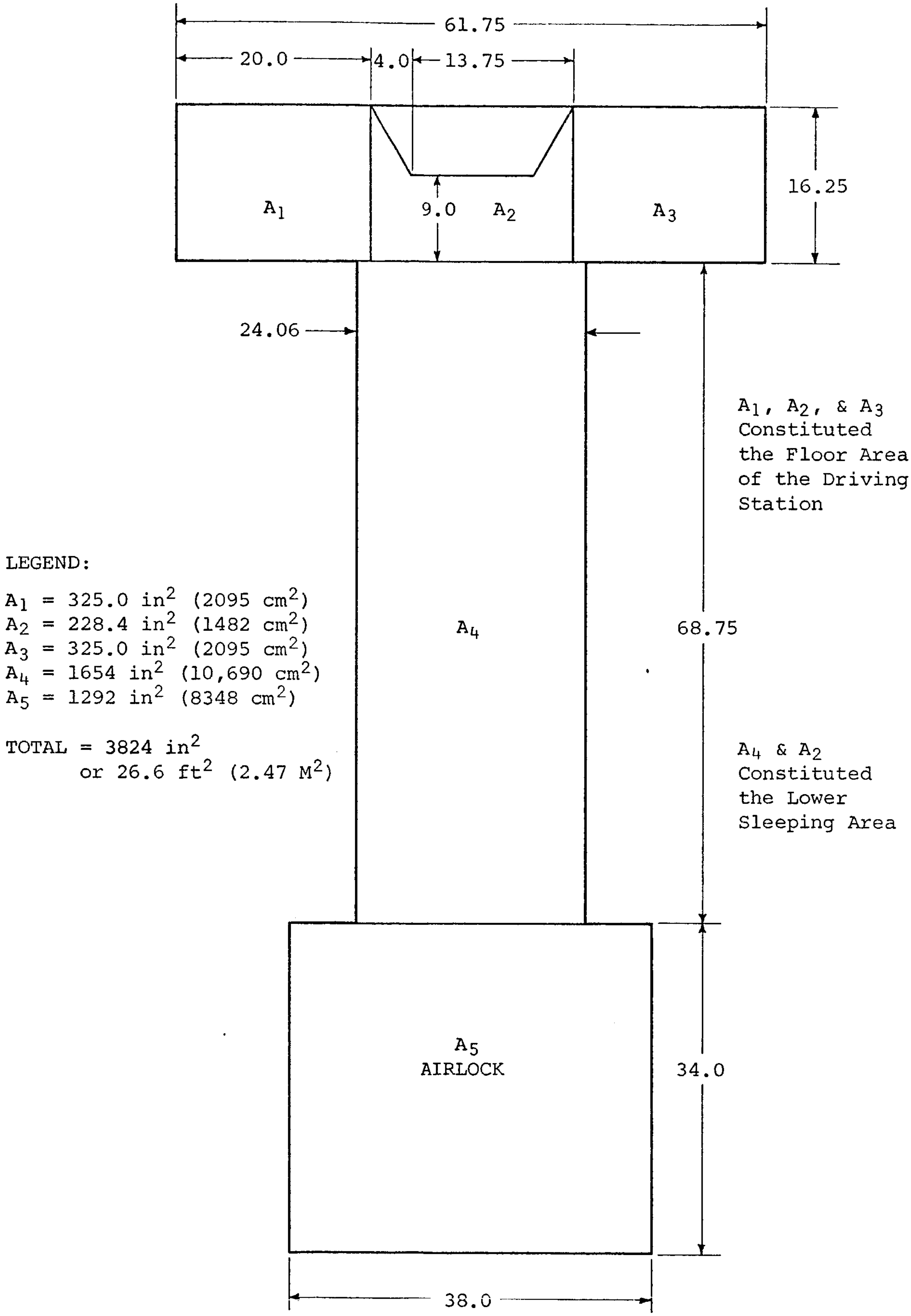

FIGURE 13. LUNEX II FLOOR AREA

4.2.8.2 Free Volume Requirements

In extensive studies performed for the MOL, Matrix Corporation scientists estimated the minimum free volume for the two-man, thirty-day mission to be 150 cu. ft. per man (Eberhard 1966). From the information surveyed and analyzed for this evaluation, extrapolations to one-year missions can be made and free volume requirements estimated for various crew sizes and mission duration. Table 32 summarizes certain of these results for two and four man crews for missions of 10, 30, 60, 90, 180, and 365 days. The most striking feature of these free volume estimates is their variability. For thirty-day missions investigators have estimated free volume requirements ranging from 90 cu. ft. to 260 cu. ft. Review of the literature also indicates that inadequate controls have been applied to the free volume investigations, that generalizations have been based on insufficient, and in some cases, inadequate data, and that free volume requirements have not been subjected to a thorough enough analysis and integration. It is assumed that these experimental and conceptual deficiencies in the studies have at least contributed to the wide variability evidenced in the free volume estimates.

The majority of these studies cited in Table 32 were concerned with the free volume requirements associated with an orbital space mission where the astronauts are more or less confined to the cabin area of the vehicle. On the lunar surface

TABLE 32.

SUMMARY OF FREE VOLUME ESTIMATES

Free Volume Estimates Per man (cu. ft.) For Different Investigators

TWO MAN CREW STUDIES

Duration	1	2	3	4	5	6	MOLAB	LESA	LUNEX II
Undefined	-	-	-	-	-	-	200	382	58
10 day	240	95	150	75		75-180			
30 day	260	160	150	90		140-330			
60 day	280	200		100		180-410			
90 day	290	250		105		270-540			
180 day	310	340		110		360-670			
365 day	325	410		115		360-670			

FOUR MAN CREW STUDIES

Duration	1	2	3	4	5	6
30 day	280			110		
60 day	310			120		
90 day	330			130		
180 day	350			135		
365 day	360			140		

References:

1. Helvey, W. M. et al.

2. Douglas Aircraft Free Volume Study

3. Fraser, T. M.

4. Davenport, E. W. et al.

5. Cramer, E. H., and Flinn, D. E.

6. Celentano, J. T., Amcrelli, D., and Freeman, G.

the free volume lower limits can be decreased since crew men can egress the vehicle and move about the lunar surface. The incidence of surface activity during a lunar mission should greatly exceed the incidence of extravehicular activity (EVA) in an orbital mission since astronaut stabilization, safety, and rescue will not be the critical problems on the moon as they are in orbital flight. Since astronauts can exit the vehicle more frequently to stretch and exercise their limbs while performing mission related activities, they need less free volume within the vehicle than they would if they were confined throughout the mission.

This assumption was supported by Haaland (1966) in his report of the LUNEX II simulation described above. This simulation had two subjects confined to a minimum volume cylindrical shaped MOLAB for 18 days. The free volume was 57.7 cubic feet per man in the living space and 81.7 cubic feet per man in the living space and air lock combined. Free volume estimated in Table 32 for a two-man crew for 10 day mission duration begin at 75 cubic feet/man; therefore, the volume of the LUNEX II was on the low end.

The work/rest schedule for the LUNEX crew was 16 hours on, 8 hours off. Their diet consisted of 3,000 calories per day with four means a day. Throughout the simulation crew men performed driving tasks, monitoring and navigational activities, and daily EVA on a treadmill in a full inflated pressure suit. Measures of their performance and physiological status were recorded throughout. The primary result of the study, as stated by the investigator, was that "two qualified subjects could maintain daily performance levels and physical condition for an 18-day simulation with no observable adverse effects or trends that could be attributed to either the minimum interior free volume of the simulator or to the duration of time spent in the simulator" (Haaland, 1966, p. 53).

4.2.8.3 Space Suit

In the analysis of extravehicular engineering activities (EVEA) North American Rockwell scientists describe the space suit assembly to be used in the Apollo Lunar program, the A7L. This suit, configured for lunar surface EVA operations, is defined as the Extravehicular Mobility Unit (EMU). The EMU systems and subsystems required to provide a habitable environment on the moon include the following: a pressure garment assembly (PGA) with associated subsystems (helmet, gloves, etc.); extravehicular visor assembly (EVVA); liquid cooled garment (LCG), portable life support system (PLSS); and emergency oxygen purge system (OPS). The PGA is an anthropomorphic emsemble which maintains a habitable environment for the astronaut while pressurized or unpressurized. It protects the astronaut from the space environment through maintaining a suitable atmosphere and pressure, thermal control, communication and protection from radiation and meteorite encounters.

Pressurizing media for the PGA is oxygen (at 3.7 PSIA) from external sources. The PGA helmet is bubble shaped, constructed of clear lexan. The astronaut's head is free to move within the confines of the helmet. Vision from the helmet is limited by the location of the torso necking.

The PGA glove is a close fitting, five finger nylon tricot/neoprene design which provides limited manual dexterity and tactile feedback. Cable restraints are incorporated into the glove design to limit its extension during pressurization. This glove is primarily used for intravehicular operations. A loose fitting beta cloth and chromel glove is worn over this glove to provide thermal/meteoroid protection during EVA.

The remaining components of the basic PGA are included in the torso limb suit assembly (TLSA). This fabric covered anthropomorphic garment has glove and helmet attachments, presurrizing gas supply and distribution, communications and bio-instrumentation, body waste collection and limb/joint mobility. Flexible joints are located at wrists, elbows, shoulders, hips, knees, and ankles. The waste management system includes a urine collection/transfer assembly and a fecal collection system. The bio-instrumentation system provides capability to continuously monitor the astronaut's heart rate and respiration rate (Samson, 1968).

Effects of mobility restrictions on lunar surface operations were described by the Apollo Lunar Science Program report of planning teams (1964). Due to the suit, body movements will be restricted such that squatting and kneeling will take much more time and effort. Lifting the arms above shoulder height is difficult and putting a hand in front of the face requires a definite effort. Hand movements are restricted by the glove and gripping of objects of 1.5 inches in diameter for long periods of time will be difficult. Looking down at one's feet is difficult. According to LaFevers and Mason (1965), walking up inclines will require some performance support. Neither the lunar walker or Jacob's staff seemed adequate. These investigators also state that performance of a task within 12 inches from the ground is very difficult. Helmet design was such that fogging of the visor was observed and downward vision was difficult.

CHAPTER V.

ASTRONAUT CAPABILITIES AND LIMITATIONS

From an analysis of lunar surface operations being planned for early Apollo, Apollo, and AAP missions, a number of representative astronaut tasks were selected. The criteria for task selection is that the total list of tasks encompasses the range of potential effects of lunar environment factors on human performance. These effects are identified for each task for each environmental factor described in Chapter II (size, atmosphere, temperature, topography, lighting, and radiation). The fact that effects have been identified for tasks and environmental factors is indicated in Table 33.

5.1 TASK 1 - Vehicle Inspection

This is primarily an inspection of the structural integrity of the vehicle. Any conditions that may limit the mission, or prevent the return of the vehicle to orbit must be detected.

Operational Environment:

- The landing site is in a relatively flat area.
- The task is performed during day-light hours, with the sun at a relatively low angle of inclination.

Performance Requirements:

The vehicle inspection is primarily a visual task. The astronaut will be looking for signs of damage such as cracks, buckling, punctures, etc., while circumambulating the vehicle.

TABLE 33.

ENVIRONMENTAL EFFECTS FOR REPRESENTATIVE TASKS

TASKS	ENVIRONMENTAL FACTORS						
	SIZE	ATMOS-PHERE	TEMPER-TURE	TOPO-GRAPHY	LIGHTING	RADIA-TION	GRAVITY
Vehicle inspection	No	Yes	No	No	Yes	No	Yes
Surface Survey	Yes	Yes	No	No	Yes	No	No
Self-locomotion	No	No	Yes	Yes	Yes	No	Yes
1/6 g acclimation	No	No	Yes	Yes	No	No	Yes
Astronaut observation	No	Yes	No	No	Yes	No	No
Sample collection	No	No	No	Yes	No	No	Yes
Sample identification	No	No	No	No	Yes	No	No
Sample storage	No	No	No	No	No	No	Yes
Unloading	No	Yes	No	No	No	No	
Seismic experiment deployment	No	No	No	Yes	Yes	No	Yes
Package leveling	No	Yes	No	Yes	Yes	No	Yes
Use of hammer	No	No	No	Yes	No	No	No
Use of scoop	No	No	No	Yes	No	No	No
Manual deployment of MOLAB	No	No	No	No	No	No	Yes
TV lens changing	No	No	No	No	No	No	Yes
Vehicle control	Yes	Yes	No	Yes	Yes	No	No
S band antenna deployment	No	No	No	Yes	No	No	Yes
Lunar drill deployment	No	No	No	Yes	Yes	No	Yes

This task must be undertaken through all lighting conditions. The visual capability to perform this task successfully will be influenced by several variables. The capabilities and variables are listed below:

Visual Capabilities	Variables
• Perception of form, contour & pattern	• Direction of light source
• Visual acuity	• Illumination of object
	• Familiarity with object

Effect of Lunar Environment on the Visual Task of the Vehicle Inspection

1. Size - NONE

2. Atmosphere - the lack of an appreciable lunar atmosphere should not degrade the astronaut's performance. If a behavioral change were expected, it must be assumed that an improvement in performance would occur, due to reduced distortion by the atmospheric layer.

3. Temperature - NONE

4. Topography - NONE

5. Lighting - the man must traverse 360° about the vehicle. This means that the task must be performed under all lighting conditions, from bright sunlight through darkest shadow. In the situation where the sun is from behind his line of sight, his acuity in the perception of form, contour and pattern should be extremely fine. This is the result of the high illumination level and high contrast ratio of a black appearing crack on the white background, or white structure of the vehicle against the black background of space.

   Once the astronaut enters the area of shadow, however, his performance would be expected to deteriorate markedly. With the sunvisor attenuating 90% of the visible radiation, the astronaut is working in approximately a 10^2 ft. L. scene when the sun is behind him. From this, he enters an area having 10^{-6} ft. L. Normal adaptation of the eye for these intensities should be at least 20 minutes. Without allowing time for the adaptation to occur, the astronaut should not be able to perform the visual inspection on the "dark" side of the ship and might not be able to perform such a basic task as walking.

A second problem exists due to the low contrast ratios that would exist. A crack, puncture, or buckled structural member is assumed to be dark in nature. The astronaut would be forced to discriminate between a "pure" black object on a "pure" black background, an impossible task. Buckling in an area that would be framed by the sun would be obvious, but the probability of this occurring is very low.

At several points in his walk around inspection, the vehicle within his field of view will be partially submerged in shadow. This will occur when the astronaut is transitioning from the sun-side to shadows, and when returning into the sun-side. Those areas illuminated by the sun will readily allow for the inspection, while those in the shadows will appear black.

Transitioning from the black shadows into sunlight will not produce a major problem such as found with dark adaptation, since the response time of the eye in light adaptation is much more rapid.

Some type of artificial light source should be supplied so that the astronaut can complete his visual inspection while on the side of the ship away from the sun.

6. Radiation - NONE

7. Gravity - NONE

5.2 TASK 2 - Surface Survey

This task entails the astronaut's visual surveillance of the lunar scene. This survey will be performed for orientation, navigation, and photography purposes.

Operational Environment

In early Apollo the LM vehicle will land at the terminator where the angle of incident sunlight will be approximately 74 degrees from the vertical.

Performance Requirements

Unspecified

Effects of the Lunar Environment on the Surface Survey Task

1. Size - the smaller diameter of the moon may lead to errors in distance estimation. This smaller diameter will reduce the actual distance to be scanned.

2. Atmosphere - the absence of atmospheric haze may further degrade the judgment of distance. Lack of an atmosphere also increases the contrast between lighted and shadowed areas.

3. Temperature - NONE

4. Topography - NONE

5. Lighting - Due to the problems of glare, the retro-reflection of light on the moon and the high contrasts between lighted and shadowed areas, the visual information available to the astronaut will vary with his direction of view. When looking toward the sun the astronaut receives minimum light from the surface, due to the preponderance of shadows and the retro-reflection of light. He also is confronted with maximum glare since the solar disc could intrude into his field of view. When the astronaut looks away from the sun, he is confronted with maximum light from the surface, minimum shadows, and minimum glare from the sun.

6. Radiation - NONE

7. Gravity - NONE

5.3 TASK 3 - Self Locomotion

This task entails the astronaut's walking about the surface encumbered and unencumbered.

Operational Environment

The gravity and topographic environment of the moon.

Effects of Lunar Environment on Self Locomotion

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - the exertion of walking up inclines coupled with the extreme variations in temperature between parts of the body in sunlight and shadow may place great loads on thermal regulation capabilities of life support systems.

4. Topography - the reduced traction associated with loose incoherent surface could impede walking performance to the extent that support equipment are required.

5. Lighting - same effect as defined in TASK 2.

6. Radiation - NONE

7. Gravity - the reduced gravity of the moon may require a locomotion gait different from that experience on earth. On the moon, the astronaut may traverse the surface in a loping manner covering more surface in each stride. The effect of gravity on energy expenditures associated with walking on the moon is uncertain. Some investigators predict an increase in metabolic rates while others postulate a reduction due to decreased muscle strength required to maneuver.

5.4 TASK 4 - 1/6 g Acclimation

This is principally an orientation period for the astronaut during which he is expected to familiarize himself with the gravitational field on the moon, and its effects on his locomotive ability.

Operational Environment

- The landing site is a relatively flat area

Performance Requirements

The 1/6 g acclimation period is the time during which the astronaut becomes accustomed to the lunar environment. While in this acclimation period, he is expected to bend or stoop to pick up contingency samples. The astronaut must be able to maintain his balance and control his directional movements. He will learn to move at a controllable rate and adjust his balance and muscular action to the unusual blend of forces required to change direction or stop. This will be his first real experience with the new combination of inertia and weight associated with the lunar environment. The prime factors affecting man's locomotive ability in the lunar environment are listed below.

Ambulatory Capabilities	Variables
walking	1/6 g traction inertia

Effects of Lunar Environment on the 1/6 g Acclimation Task

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE
4. Topography - Since the astronaut will be experiencing new sensations on his first lunar excursion, the more level the terrain he will encounter, the more rapidly he will be able to adapt to the 1/6 g environment with a minimum degree of risk to himself or his life support system.
5. Lighting - NONE
6. Radiation - NONE
7. Gravity - on the lunar surface the astronaut will have to move very slowly at first. This will be his first experience of walking in an environment that allows for differences in traction and inertia which affect his "normal" 1 "g" locomotive ability. He will have acclimate to a to a reduced traction environment where, if he tried to

make rapid leg movements such as in running (from a standstill), he would encounter a great deal of slippage, and might in fact fall.

In this environment, any change of direction from rapid movement would be difficult. While his mass has been reduced by 1/6, his inertia would remain the same as if he were on earth. He, therefore, must learn what motions and maneuvers are possible to allow for the control necessary to complete the mission.

It should be noted that while in the spacesuit, simulated lunar locomotion studies have indicated that the astronaut will not be able to move as rapidly as he does on earth. In fact, during the initial acclimation period, he should move at a pace well below his maximum capability.

5.5 TASK 5 - Observations of Astronaut On the Lunar Surface by the Astronaut in the LM

The philosophy of NASA as to whether one or both astronauts will be allowed onto the lunar surface at the same time is not clear. At differing times, it has been stated that there will be only one man on the surface at a time, while others have said that both astronauts will be on the surface at the same time. The present task/task element assumes that at least for early Apollo there will be only one astronaut performing EVA on the lunar surface during any given mission segment.

Operational Environment

The astronaut will be in the LM observing his companion performing various mission tasks. The observer in the LM will be responsible for recording the other astronauts activities and maintaining surveillance over his companion's safety.

Performance Requirements

The astronaut in the LM will be performing the visual task of monitoring his companion's surface activities. This visual task will be performed through the LM windows. The visual task involves several variables. The capabilities and variables are listed below:

Visual Capabilities	Variables
Acuity	Brightness Contrast
	Glare (brightness ratio)

Effects of Lunar Environment on the Observations of an Astronaut On the Lunar Surface by the Astronaut in the LM

1. Size - NONE

2. Atmosphere - depending on the relation of the LM windows to the sun, the astronaut in the cabin might have his acuity impared by retro-reflection or direct sunlight creating glare on the LM windows. Also, as indicated by Dr. Foss (1968): "The astronauts in the LM will have difficulty seeing ahead, and that the maximum washout of detail occurs between the windows".

3. Temperature - NONE

4. Topography - NONE

5. Lighting - if the LM windows face into the sun, then glare off of the window could once again impair the vision of the astronaut inside the capsule.

6. Radiation - NONE

7. Gravity - NONE

8. Other - there are periods of time (prior to erection of the communications antenna) that both astronauts will be out of visual and voice communications. This can occur when the walk around inspection is being conducted, due to the orientation of the windows and the potential proximity of the surface based astronaut to the vehicle. If close proximity is maintained, then the LM structure might interfere with transmission of voice communication between the PLSS antenna and the antenna located on the LM.

5.6 TASK 6 - Collecting Grab Samples of Surface Material

This is primarily a task which could be performed while the astronaut is acclimating to the 1/6 "g" condition. As such, it is performed early in the mission, so that samples might be brought back to earth even if the astronaut's should have to abort the mission shortly after the beginning of their EVA activities.

Operational Equipment

- The landing site is in a relatively flat, smooth area.
- The astronaut has his contingency sample kit with him.
- The task is performed during daylight hours, with the sun at a relatively low angle of inclination (approximately 75^{o} from the vertical).

Performance Requirements

Collecting contingency samples of surface material is primarily a perceptual motor-balance task. The astronaut will be required to locate samples in his immediate area, retrieve them by hand, or with the aid of a tool, and bag it in a plastic sample bag. The perceptual motor-balance capabilities will be influenced by several variables. These are listed below:

Perceptual Motor-Balance Capabilities	Variables
Balance	1/6 "g"
	C.G.
	Topography

Effects of Lunar Environment on the Collecting Grab Samples of Surface Material Task

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - NONE

4. Topography - Simulation studies have indicated that a suited astronaut has great difficulty performing any task that is below 18 inches from surface level (higher reaches are recommended). It is quite possible that the astronaut will try to retrieve a sample that is at surface level, without the aid of a tool. In such a circumstance, it is conceivable that he would loose his balance due to the restriction of his suit, unknown texture of the lunar surface, and higher c.g. (the result of his PLSS).

5. Lighting - NONE

6. Radiation - NONE

7. Gravity - while balance may not be greatly affected directly by 1/6 g, the reduced gravity does decrease traction between the subject and the surface being traversed. This might lead to a greater degree of instability of the astronaut in situation when he must bend over.

5.7 TASK 7 - Perform Identification of Samples

Before actually retrieving or picking up a sample and after retrieval, before storage of the sample, the astronaut must identify and classify it as one to be returned to earth.

Operational Environment

The astronaut will survey the terrain for potential samples while traversing the surface.

Performance Requirements

The astronaut will be required to recognize patterns and forms to differentiate loose rock from general terrain.

Effects of Lunar Environment on Identification of Samples

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE
4. Topography - NONE
5. Lighting - visual performance will vary with the direction of viewing. Due to high contrast conditions and preponderance of shadows due to the low sun angle, the task could be difficult without some source of artificial illumination.
6. Radiation - NONE
7. Gravity - NONE

5.8 TASK 8 - Store Samples

During most of the early Lunar missions, the astronauts will be required to collect samples of the lunar soil and then to weigh them prior to bagging and storing them.

Operational Environment

On the initial flights, the terrain will be relatively flat and smooth around the landing site. In later missions, as the astronauts stay for longer periods of time on the lunar surface, their traverses will take them into various types of terrain. This might include steep slopes as well as crevices.

Performance Requirements

On the initial flights, the return payloads will be limited. The astronaut will be required to estimate the weight of his sample retrieval kit and samples, some expenditure of energy might be eliminated. Astronaut fatigue would be reduced through the elimination of excessive weight handling.

The capabilities and variables affecting weight perception are listed below:

Perceptual-Motor Capabilities	Variables
Perception of weight	Kinesthetic stimulation
	Proprioceptive stimulation

Perception of Weight on Earth

On earth the perception of weight is primarily due to proprioceptive stimulation. The studies conducted have been oriented to the perception of differences between two weights, rather than absolute weight estimations. Results indicate that weight perception follows a law which states that relative differences in stimulation are equally perceptible.

Effects of Lunar Environment on the Weight Perception of Lunar Samples

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE
4. Topography - NONE
5. Lighting - NONE
6. Radiation - NONE
7. Gravity - The kinesthetic stimulation that is effective in extremely light weight perception will be masked by the astronaut's glove. The proprioceptive stimulation should remain similar to that on earth. There probably will be a

period of adaptation to the reduced gravity environment which the astronaut will have to undergo. During this period, he will become familiar with the amount of energy and muscular expenditure needed to perform specific movements involving weight-force perception. Prior earth simulation training might facilitate this adaptation period.

5.9 TASK 9 - Unload Experimental Packages

Originally, the first astronauts on the lunar surface were scheduled to deploy five (5) experimental packages for scientific data gathering. This schedule has been modified so that the original experimental packages are scheduled to be deployed by the second group of astronauts. The first group are scheduled to deploy three (3) experimental packages designated - a solar wind experiment, passive seismometer, and laser ranging retro-reflector.

Operational Environment

On the initial flights, the terrain around the LM should be relatively flat and smooth. For the first missions, the astronauts will limit their activities to this area under daylight conditions.

Performance Requirements

In unloading the scientific equipment packages from the LM, the astronauts should have the sun to their backs. In unfastening and picking up the equipment, the astronauts must be able to view the object to be moved. This then is primarily a visual task. The capabilities and variables which effect the astronaut's ability to perform this task are listed below:

Visual Capabilities	Variables
Visual acuity	Level of illumination
	Contrast between object and background

Visual acuity is a function of the level of illumination and the contrast between the object being viewed, and the background.

In their review of the literature, Roth and Finkelstein (1968) give the following summary. "....a reduction in any one factor background luminance, size, or contrast may be compensated for by an increase in one or more of the others .... The chief effect of reducing contrast is a shift of the curve upward in the direction of increased target size of 50% probability of resolving parts of a target .... when it gets darker, objects must be a lot blacker or lighter than their background to be seen; and, at any level of luminance, small objects must have more contrast in order to be seen, than large objects."

Effects of Lunar Environment on the Perception (Visual) of Objects to be Unloaded From the LM (Experimental Packages)

1. Size - NONE

2. Atmosphere - Due to the lack of atmospheric scattering of light rays, it is anticipated that deep shadows will have effectively no luminance, that is 10^{-6} ft. L or less. Since the astronaut will be placing his body between the sun and the object to be unloaded, all objects in this shadow, including the experimental package should be in this luminance range. For all intents and purposes, if the astronaut were to use his visual apparatus to locate hand-holds or release fasteners, he would have to depend upon some other sense modality to complete this task, since he should not be able to see in this luminance.

3. Temperature - NONE

4. Topography - NONE

5. Lighting - See Atmosphere

6. Radiation - NONE

7. Gravity - NONE

5.10 TASK 10 - Deployment of the Seismic Cable and the Detectors for the Active Seismic Experiment

This experiment should be conducted on relatively flat, smooth terrain near the LM. The experiment would be conducted during daylight hours.

Performance Requirements

As recorded in Technical Letter: Astrogeology-12 - this task involves the following steps.

1. Subject removes equipment, Apollo Lunar Surface Experiment Package (ALSEP) and staff sections, from the Lunar Module (LM) descent storage bay.

2. Places ALSEP at suitable position.

3. Assembles staff sections. The lower position of the staff contains a squib-fired thumper for inducing energy into the ground. The upper portion contains a compartment for the seismic cable. The cable is marked at 5-meter intervals.

4. Plugs seismic cable into the ALSEP, and carries the staff during the operation.

5. Walks 20 meters from ALSEP while paying out seismic cable.

6. Kneels and pushes the first detector into the ground.

7. Walks 50 meters while paying out seismic cable.

8. Pushes the second detector into the ground.

9. Walks another 50 meters and pays out seismic cable.

10. Kneels and pushes the third detector into the ground.

11. The subject rises, turns around, and with the staff placed at the third detector, charges the capacitor in the staff and fires a squib.

12. The subject then walks 5 meters back along the cable and places a second squib into position for firing, charges the capacitor in the staff, and fires the squib. This is repeated at 5 meter intervals within 5 meters of the first detector (a total of 20 times).

In the simulations conducted, the cable was color coded for 5 meters prior to the location that the detector was to be placed. For the astronaut on the lunar surface, this becomes a visual problem of color detection.

Visual Capabilities	Variables
Color detection	wavelength
	contrast

"Experimental findings concerning visual acuity and color of the illuminant have been somewhat contradictory. When there is a large luminance contrast between test object and background, visual acuity varies only slightly with wavelength and is generally best near the middle of the visible spectrum, if all test objects are of equal luminance. Reducing the luminance contrast between test objects and background degrades acuity similarly at all wavelengths so there is little, if any, interaction between wavelength and contrast." (Roth and Finkelstein, 1968)

Effect of Lunar Environment on the Perception of Color Used in Coding for Lunar Experiments

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - NONE

4. Topography - if in laying out the cable, the astronaut has to walk back along the cable with the sun at his back, it is possible that the retro-reflection from the lunar surface might degrade his perception in this visual task. This would be especially true if the color used was similar to the lunar surface. In this case, the reduced color and brightness contrasts between the cable and the lunar surface would reduce the detectability threshold of the astronaut.

5. Lighting - there is no reason to believe that visible radiation on the lunar surface would be so different from that here on earth, that color coding is not an effective method of conveying information to the astronauts. It should be remembered, however, that they will be wearing 90% attenuating sun visors and the selection of color codes would be made while being cognizant of the effects this visor will have on the colors selected.

6. Invisible radiation - NONE

7. Gravity - NONE

5.11 TASK 11 - Leveling of Experimental Packages on the Lunar Surface When They are Being Deployed

Operational Equipment

Several of the experimental packages destined for deployment on the earlier Apollo Missions have to be deposited on the lunar surface, and then leveled prior to completion of the deployment. An example of this type of equipment is the antenna. This task is to be completed in the daylight hours on relatively smooth, level terrain.

Performance Requirements

The last portion of the deployment sequence for the antenna is:

Receive azimuth and elevation offsets.

Enter azimuth offset.

Enter elevation offset.

Observing bubble level, adjust leveling knobs.

Observing sun compass, adjust alignment knob.

Re-check level and walk to LM.

(ALSEP Configuration A, L. Marrus, 1968)

The astronaut, in this task/task element, is required to visually make estimations of leveling via the bubble, and manipulate the antenna stand via leveling knobs. This, then, is a visual-motor task.

Capabilities	Variables
Visual acuity	stimulus size
	glare
	color
tactile stimulation	stimulus size
	stimulus shape

Effect of Lunar Environment on the Leveling Tasks to be Performed in Equipment Deployment

1. Size - NONE

2. Atmosphere - Care must be taken by the astronaut not to interfere with the sunlight impinging upon the leveling device containing the bubble or the leveling controls located on the antenna legs. If this should occur, then these critical elements will be cast into the 10^{-6} ft. L. darkness associated with lunar shadows. Under these lighting conditions, the astronauts should not be able to complete their assigned tasks.

3. Temperature - NONE

4. Topography - It is assumed for this analysis that the lunar topography in the area that the antenna is to be erected will be relatively flat, so that minor corrections are needed.

5. Lighting - The visual acuity of the astronaut will be degraded if he is in an environment where glare exists. The glare that could effect his performance could be due to retro-reflection from the surface of the moon reflected light from equipment in the area, including from the antenna support structure, or sunlight reflected from the surface of the LM. The intensity of glare on the lunar surface (believed to be approximately 90% of the sunlight) would severely deter completion of this task.

   Due to the high intensity of the ambient light, the color of the liquid and the size of the bubble in the leveling device could become important factors in completion of the task/task element.

6. Radiation - NONE

7. Gravity - It must be assumed that the control handles and leveling bubble are in close proximity so as not to make the astronaut perform the extra motions of bending to make adjustments to the antenna legs, then standing to estimate the degree of level. This would only increase the metabolic cost of the astronaut, and potentially induce a lack of balance in the reduced gravity environment. It is further assumed that the knobs have been conformed for ease of astronaut handling, especially since he is working in a reduced tactile field due to his gloves.

5.12 TASK 12 - Use of Multi-purpose Geological Hammer for Geological Sampling

This is primarily a task which could be performed at any time during Stage I or Stage II missions depending upon whether geological surveying is scheduled or not.

Operational Equipment

Not having details of the operational equipment planned for the initial Apollo Missions, we are using the original Martin Company design for this task/task element analysis. The hammer has a 3.9 lb. head, which is reversible so that it can be used as a hatchet or a broad-blade pick. To assist the astronaut, the handle was made adjustable (18 or 28 inches), and the grip was contoured to the shape of an astronaut's glove (right-hand), while incorporating a grip guard so as to reduce the possibility that the astronaut would rap his knuckles while using the tool.

Performance Requirements

Use of the multi-purpose geological hammer is primarily a motor task. The astronaut after locating a rock specimen and deciding that is too large for him to handle, will have to take a portion of the sample via shaving or breaking it into smaller more manageable parts. This is primarily a motor task. The capabilities and variables that will effect this task are listed below.

Capabilities	Variables
hand and arm movements	energy expenditure
	muscle fatigue
	balance

Effect of Lunar Environment on the Motor Task of Using the Multi-purpose Geological Hammer

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - NONE

4. Topography - It is conceivable that the astronaut will have to work in close proximity to the lunar surface while collecting his samples. It is quite possible that a kneeling position would have to be maintained while using the hammer. Due to pressurization of the suit, this could impose balance problems that would be detrimental to the completion of the task. In addition to this constraint, Martin studies have indicated that the energy expenditures involved in this task

are extremely high. This coupled with the finding that grasping or holding objects with the gloves induces hand fatigue rapidly will degrade the astronauts capability to perform with a high degree of efficiency. As Martin (Crouch, 1965) has reported: "The feasibility test revealed a tendency for the space suited subject to relax his grip and drop the hammer after the fatiguing task of hammering a sample for several blows".

5. Lighting - NONE

6. Radiation - NONE

7. Gravity - NONE

5.13 TASK 13 - Use of the Multi-purpose Scoop in Geological Sampling

This is a tool that might be used in any geological sampling mission in Stage I or in Stage II missions. Not knowing the equipment list for the Early Apollo missions, it is assumed that such a tool might be on these flights.

Operational Equipment

In the 1965 Martin evaluation, this tool was described as follows:

> "Multi-purpose Scoop - A scoop with a multi-positionable bowl was developed for procuring loose-lying samples. The device can function as a spade, hoe, or scoop, by adjusting the bowl at an angle of 180°, 90°, or 45°, respectively, to its handle. Several additional attachments were also designed for use with the basic scoop assembly. These include:
>
> a. Sample drive tubes - these tubes can be quick-connected to the end of the sample scoop handle, and subsequently screw-twisted or hammer-driven into a relatively soft surface such as pumice.
>
> b. Chisel - the chisel attachment to the sample scoop handle can be used for prying, or scribing orientation marks.

c. Brush - the small wire brush attachment can be used for removing light dust layers from lunar surface specimens."

On the initial flights, this tool will be used on relatively level terrain near the LM. As stay time increases, and traverses become longer and more complex, it is anticipated that the tool will have to be used in a variety of environments.

Performance Requirements

The use of the multi-purpose scoop is primarily a motor task involving hand and body coordination. Desired specimens would be scooped up or pried out of the lunar surface so that they could be placed into the sample containers. The capabilities and variables that will effect this task are listed below.

Capabilities	Variables
Hand movements	muscle fatigue
Body movements	balance
	leverage

Effect of the Lunar Environment on the Motor Task of Using the Multi-purpose Scoop in Geological Sampling

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - NONE

4. Topography - In the use of this tool, it is assumed that the astronaut is fully acclimated to the lunar environment. This indicates that he has adapted to the gravitational field around him. In prying samples from the lunar surface, the astronaut will be using leverage that involves body movements. The Martin Company (1965) made the following comments concerning such movement following their simulation testing.

"Theoretically, an unrestrained astronaut should be able to exert maximum forces and torques equal to 1/6th of his body weight (excluding apparel, equipment, etc.) on the lunar surface. Greater forces can be obtained when the astronaut is restrained, or when leverage can be utilized between the surface and the work source. The study indicated that the unrestrained astronaut could utilize but 35% to 68% of his 1/6th weight capability in applying torque and force....During an exploration excursion of the lunar surface, the ability of the astronaut to restrain torquing forces will depend partially upon the characteristics of the surface materials." Such forces might well be required when using the chisel attachment for prying loose lunar samples. Balance is of prime importance in the application of leverage under lunar conditions. As stated earlier, this capability should not be degraded in the lunar environment.

5. Lighting - NONE

6. Radiation - NONE

7. Gravity - NONE

8. Other - Once again, the apparent increased muscle fatigue associated with fine hand movements and grasping actions might become an important factor in the successful completion of the task when using this tool.

5.14 TASK 14 - Unloading Equipment (manual deployment of MOLAB)

On longer duration missions, the astronauts will be supplied with surface vehicles. These will be delivered by a LM truck approximately three weeks prior to the crew landing in a LM taxi. The MOLAB will be landed and unloaded via remote control. In the event that the automatic deployment is unsuccessful, the crew will attempt to deploy the vehicle manually. In this analysis certain assumptions will be made due to lack of information regarding official procedures. The basic assumption to be made is that the automatic deployment system involves the use of pyrotechnic devices. Since the astronaut will be working with a system that has malfunctioned in some undetermined manner, he must be safe-guarded by the existence of a dead-face method for the pyro system. Once the failed system is rendered safe, he would begin his manual deployment.

Operational Environment

- The landing site is in a relatively flat area.
- The task is performed during daylight hours, with the sun at an undetermined angle of inclination but with sufficient illumination.

Performance Requirements

The manual deployment of the MOLAB is primarily a motor task involving torquing forces and gross hand coordination movements. It is believed that the astronaut will be forced to loosen numerous fasteners and tie-downs. It is further assumed that these fasteners will be of the bolt and captive screw type. While lighting will obviously play an important factor in this exercise, it is not considered as strongly in this analysis as are the motions required to free the above mentioned fasteners. The capabilities and variables required to perform this task are listed below.

Capabilities	Variables
Torquing and screwing motions	Traction
	Hand fatigue

Factors Affecting Torquing and Screwing Motions in the Manual Deployment of MOLAB

1. Size - NONE

2. Atmosphere - NONE

3. Temperature - NONE

4. Topography - NONE

5. Lighting - NONE

6. Radiation - NONE

7. Gravity - Simulation studies at the Langley Research Center have indicated that the astronaut in the 1/6th "g" condition will encounter reduced tractional forces. Other studies conducted by The Martin Company (1965), and Lockheed (1967) have indicated that the lunar environment reduces the astronauts efficiency in both torquing and screwing tasks. Shavelson (1968) summarizes the findings of this research and quotes the authors in the following manner. "The performance decrement observed in lunar gravity and the various clothing conditions point at the necessity of considering human engineering design countermeasures ... while considerable attention is currently being given to performance aids for assisting the astronaut in the zero gravity environment (Pierson and Geller, 1965), relatively little attention has been devoted ... to facilitate lunar maintenance and operational tasks (Holmes, 1965) ... Handholds should be provided for the astronaut primarily as a method for obtaining a satisfactory position relative to the task. However, if possible, the astronaut should not be required to use his hands in steadying his position relative to his equipment task since this would limit his ability to use both hands in accomplishing tasks. Further, it appears that a one-hand grip would not be sufficient to steady his position for many tasks. Properly spaced and distributed toe-holds and tether anchor points appear to offer promise in helping to steady the astronaut's position for tasks involving force application such as the torquing task. Holmes (1965) investigated tether concepts ... and concluded that a single tether located from the navel area of the suit to the task was the best candidate. Further research is required. It also has been pointed out that the pressurized suit prohibited performance in extreme positions. In addition to the tethers and handholds, extravehicular work may require lunar ladders to toe-holds on the

side of structures where work is required above the astronaut's shoulders. Also, work areas extremely close to the lunar surface should be avoided where possible." These conclusions were based on the finding that a torquing task took 513% more time in a reduced (1/6th "g") environment when the subject was in a pressure suit than a comparable 1 "g", shirtsleeve condition.

Energy expenditure should increase for these tasks over earth conditions, and hand fatigue has been cited several times when the astronaut is forced to grasp a tool through the glove. These factors should add to the deterioration of astronaut performance in this manual deployment task.

5.15 TASK 15 - Changing Lenses on the TV Camera

This is a task which will be performed in the earlier missions and also in later missions. It is a means of evaluating the lunar environment and it could also be used to monitor astronaut performance and crew safety.

Operational Equipment

On the earlier flights the terrain will be relatively level. In later flights, however, the terrain could vary through the complete range of lunar conditions. It is assumed that this task would be performed under daylight conditions, or, with a strong illumination source.

Performance Requirements

Changing the lenses on the TV camera is primarily a finger deterity task requiring fine finger mobility. The astronaut is required to place the lense in position and then to lock it in position with the other hand. In a study conducted by MSC (Wood, 1968) it was discovered that "any movement of the camera and/or lens resulted in the lens becoming unseated or moved out of position so that it could not be loaded to the camera. This task requires the capabilities and involves the variables listed below.

Capabilities	Variables
Fine hand-finger dexterity	Protective clothing (gloves)

Effect of the Lunar Environment on the Motor Task of Changing Lenses On the TV Camera

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE
4. Topography - NONE
5. Lighting - NONE
6. Radiation - NONE
7. Gravity - In the simulation study listed above the following results were listed. "Because of the small size of the lunar day lens (1.5 inches long and 1.15 inches in diameter), it was difficult for the subject to grasp and place into position on the camera. Combined with the lens small mass, the requirement to shift the fingers from the lens to the locking mechanism resulted in movement of the lens from the locking position. In other words, the subjects could not release the lens and move the locking mechanism without dislocating the lens in the process. Movements of the camera contributed to the the problem."

   "The telephoto lens was easily held but the subject had the same problem as with the day lens when he attempted to move his hand from the lens to the locking mechanism. Additionally, because the telephoto lens is long (4.80 inches), it was easier to tip over or move out of position by camera movements or for the subject to inadvertently strike the lens during the locking process."

It becomes apparent that the gloved astronaut will experience a marked deterioration of fine motor ability (finger-hand dexterity). For this reason, equipment should be designed for this degraded physical capability.

5.16 TASK 16 - Control of a Lunar Vehicle or Flier

On missions involving longer duration stays, the astronauts might have to be able to control a lunar vehicle or flier which would be used for long distance mapping, sample collecting, etc.

Operational Environment

The terrain might vary from relatively level to steep slopes, cliffs, or crevices. The lighting conditions could be varied from a sunlight condition with the sun at unspecified elevation levels, to a night-time situation. The astronaut could be traveling on or above the lunar surface.

Performance Requirements

In the control of either vehicle, the astronaut will have to be able to perceive and make judgments of size of objects, distances, heights, and of the slant or slope of surfaces. These visual requirements are affected by several variables, some of which are physiological while others are psychological. The capabilities and variables are listed below.

Capabilities	Variables	
Distance Size Slope	Physiological - 1. convergence 2. accomodation 3. muscular strain 4. double images 5. size of retinal image	Psychological - 1. super-position 2. clearness of outline 3. differences in lighting & shadows 4. relative motion 5. Gestalt effects 6. experience

Regardless of the environment encountered, the physiological variables associated with the perception of distance, size, and slope should remain constant with one "g" earth conditions. For this reason, they will be described under the 1 "g" condition only.

Convergence

Used primarily when the eyes are focusing on an object less than 30' from the observer. The distance cue is supplied by the sensation of strain necessary to have the eyes converge.

Accomodation

Used primarily when the eyes are focusing on a nearby object. The depth or distance cue is supplied by the tension of the muscles used in adjusting the thickness of the lens of the eye.

Muscular Strain

The six pairs of muscles controlling eye movement supply feedback information used in judging objects such as the width of a crevice.

Stereoscopic or Double Images

The eyes tend to fixate at a given point or object in space. Perception of distance from the fixation point is facilitated by the knowledge that objects in front of the fixation point appear crossed while an object further removed from the observer would appear as uncrossed double images.

Retinal Image Size

The larger the size of the retinal image, the greater the apparent size of the object.

The psychological variables associated with the control of a lunar vehicle or flier are more prone to earth-moon environmental differences. The prime factors affecting man's visual capabilities in the lunar environment are listed below.

<u>Perceptual Capabilities</u>	<u>Variables</u>
Distance Size Slope	1. <u>Interposition (super-position)</u> - used in perception of relative distance judgments. When an object partially obstructs the view of another object, the partially obstructed object is further away. 2. <u>Clearness of Outline</u> - the more clearly the outline of an object is perceived, the closer it is assumed to be. 3. <u>Differences in Lighting and Shadow</u> - Because sunlight is directional, visually from above, the objects receiving more light are perceived as being higher than objects which appear dimmer. Using a light source so that visible radiation is relatively horizontal to the surface, depressions appear to be darker than the surface, whole protrusions appear to be lighter. 4. <u>Relative Movement</u> - the more distant an object is to the observer, the more slowly it appears to approach him (if it is in front of him) or move past him. Conversely, the faster an object approaches or departs, the closer it is perceived to be. 5. <u>Gestalt Effects</u> - an object is distinguishable from its surrounds by certain characteristics. These might include texture, color, etc. While a figure does tend to be as good or complete as possible, the greater the resolution of its component characteristics, the closer it is perceived to be.

Effects of Lunar Environment on the Perception (Visual) Components Associated with Control of a Lunar Vehicle or Flier

1. Size - Having a more severe apparent curvature, astronaut perception of distance and size on the moon will differ from similar perception on earth. The astronaut perception is based on earth experiences. Many distance judgments are based on an estimation of the distance from the observer to the horizon, and the object that is being observed to the observer and the horizon. Due to the apparent greater curvatures on the moon, this perception might be distorted so that distances are over-estimated. Over-estimates might also occur in the perception of the size of objects. Many size estimations are related to the amount of area on the circumference of the visual field that is utilized by the object being viewed. Based on earth experience, such size estimations will also be over-estimated.

2. Atmosphere - Atmospheric distortion results in blurring of outline which is a cue in the perception of depth. The lack of a substantial lunar atmosphere will effect the astronaut's perception of distance, since this cue will not be present on the moon.

3. Temperature - NONE

4. Topography - The characteristics of the area being viewed will effect man's perception of depth, size and slope regardless of where they occur. Proprioceptive cues relating to the height of a cliff should remain constant. The effect of straining in the neck and head when looking up the face of a cliff is the same on earth or the moon. Perception will vary for an object viewed in a desert scene, and the same object viewed in a boulder strewn field. In one case man has objects to use as a frame of reference in making an estimation of distance and size, where in the other he does not. Since the proportions of lunar features to its diameter is much greater than similar features on earth to the earth's diameter, it can only be assumed that lunar topography will effect the astronaut's perception of depth, size and slope, which is based on his earth experiences.

5. Lighting - The differences in shadows, retro-reflection vs. reflection and collimated vs. non-collimated light source should combine to place the astronaut in a visual world different from any he has previously experienced. These will effect his perceptions.

6. Radiation - NONE

7. Gravity - NONE

5.17 TASK 17 - Deployment of the S-Band Erectable Antenna

This task involves preparations and adjustment of the antenna prior to use.

Operational Environment

Assumes a flat lunar area.

Performance Requirements

The procedures for deploying the S-Band Erectable Antenna followed those recommended by MSC. The operational sequences utilized in a KC-135 parabolic flight simulation are listed below.

"The test began with the antenna resting upright with the support handle folded. In the normal sequence the handle is extended to facilitate off-loading from the spacecraft and deployment. In the aircraft the folded handle better simulates the resulting reach limits arising from the handle penetrating the soft lunar soil. Additionally, the aircraft height constraint would not allow both sections of the antenna feed to be extended (later procedure) while the handle is extended.

After checking the antenna pre-alignment, the subject released the package seal and removed the top cap and foam spacer.

Next, the subject extended the feed. The reference procedure called for releasing the tripod legs next; but, because of possibly damaging the extended legs in restowing the feed, the feed was extended first. This did not compromise the test results of either leg or feed deployment. The restowing of the feed was necessary before the antenna could be raised onto the legs within the aircraft.

The legs were extended in sequence. After re-checking the antenna alignment the subject released the Velcro straps restraining the legs and pushed or allowed them to free fall away from the antenna.

For the purpose of this test the subject raised the antenna three times to the intermediate leg detents, evaluating different methods on each trial. Those three methods had been considered the best for lifting this antenna under the recently defined astronaut lower reach limits of 22 and 27½ inches for one hand and two hand reaches, respectively. As the present antenna design has lift straps approximately 18 inches above the T-bar (handle attachment point), this was an attempt to find a suitable method with this reach constraint.

In the first method the subject placed one hand on top of the antenna for support and the other hand in a lifting strap to subsequently raise the antenna. After the antenna was partially raised, the hand resting on the top portion of the antenna was moved down to the other strap so the antenna could be raised to the intermediate tripod position.

For the second method, the subject placed both hands evenly and as far down on the antenna as possible. He subsequently raised the antenna and 'worked' his hands down to the straps where he could then continue the lift to the intermediate position.

In the final method the subject used one folded leg to assist in raising the antenna. (The Velcro had been released and the other legs lowered away from the antenna.) After partially lifting the antenna, the hand grasping the folded leg was transferred to the antenna at a lower position than was otherwise possible. The other hand, on the opposite side of the antenna, was used to keep the antenna vertical until it could be moved down to complete the lift to the intermediate tripod position.

During the recovery portion of the flight maneuvers, between each trial, the support personnel held the antenna to keep the weight off the legs and re-positioned the legs for the next attempt.

The deployment exercise was concluded with the antenna in the intermediate tripod position. The aircraft height constraint prevented raising the antenna further."

In summarizing difficulties encountered by the astronaut/subject, the personnel assigned to the study noted problems relating to balance, reach, and two-hand manipulation. This was documented in the NASA MSC report in the following manner.

"In two of the three methods evaluated the subject was able to raise the antenna to the intermediate tripod position. As in previous simulations this evaluation involved the astronaut stability problems due to the present high center of gravity of the EMU and the low reach position of the straps used to raise the antenna ... This test confirmed that the same general reach problems exist in a lunar gravity environment but that the antenna is easier to handle due to the reduced weight conditions ... For the first method the subject used one hand on top of the antenna to assist in balancing, enabling him to reach the lift strap with the other hand. Although the subject could reach the strap, this position bordered on his low reach stability limit and required a 'push-up' action to initially raise the antenna. The position also required the hand placed on the top to be moved down to the free strap."

Using the second method, "it was necessary for the subject to 'work' both hands down to the position of the lift straps."

Problems associated with lunar visible radiation, energy expenditures, hand fatigue, topographical conditions could further reduce the astronaut's capability to perform this task.

Effects of the Lunar Environment on the Reach, Balance, and Motor Functions Associated with Antenna Deployment

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE
4. Topography - Cohesiveness of the surface could affect traction and balance.
5. Lighting - NONE
6. Radiation - NONE
7. Gravity - While the reduced gravity will adversely affect astronaut balance and reach, it will also make the antenna easier to lift and handle.

5.18 TASK 18 - Deployment of the Lunar Surface Drill

This task will involve setting up the electro-magnetic interference drill and perform drilling to a depth of 3 meters.

Operational Environment

The drilling will be performed in a flat area in sunlight.

Performance Requirements

In the evaluation of the Lunar Surface Drill, the findings of one "g" simulations are presented below. The test was conducted on the afternoon of February 23, 1968. This was a suited test programmed to follow the contractor's procedures to drill and case two 3-meter holes in the simulated lunar surface. The hole placement was to be in the same areas as Test 1 but not in previously drilled locations. The other preparation was the same as hole 1, with the exception that the Apollo Lunar Hand Tool Carrier was available as a working table. The test proceeded in a normal fashion until the equipment failed.

The drill trainer was then replaced with the Electro-Magnetic Interference (EMI) Drill Model and the test continued until there was a severe casing failure. At that point the procedural sequence was abandoned. Since we have not yet drilled in the area with the sub-surface rocks, a partial hole was drilled and then the test was discontinued.

The evaluation of the findings indicated that "when the crew member attempted to grasp the bottom of the assembly with his free hand while his other hand was on the handle", a problem occurred. "This is necessary in order to place the assembly on the ALET. It was necessary to switch the unit in order to gain a hold on it. This required a cumbersome effort.

While the crew member was deploying the rack extension leg, he found that the flange on the end of the leg was too small. This requires gloved finger manipulation which is difficult with a small diameter.

Due to the low working height the crew member had difficulty coupling the extension tubes to the power head spindle while it was on the ALHT carrier .....

The crew member found it difficult to lift the drill from the surface and grasp the handle. It required a slight rotation of the drill .....

The PLSS control box on the crew members chest would make it difficult to see the treadle drill string pilot.

The crew member indicated that his stability was marginal at the low handle height of 26 inches. It would probably be very difficult to keep a foot on the treadle and perform the required drill manipulations at this height.

When the attempt was made to engage the new drill sections with the sections in the surface, the entire drill string rotated. If the lunar material does not hold the string, there is no way to prevent this ... During this attempt to mate the strings, the new strings apparently disengaged at the power head spindle. He was unable to determine that the threads were engaged properly at both places. When the drill was motorized, both sets of threads stripped and froze at the connection ....

The drilling was continued with the remaining drill string. When the drill string was withdrawn from the hole, the treadle caught on the string was raised from the surface in several instances. This no doubt was partly due to the difficulty of withdrawing the string while keeping a foot on the treadle.

Two sections of casing were emplaced in the hole, after attaching the second two sections of casing to the emplaced casing. The reach and stability to place the drill on the casing was marginal.

Additional drill string was placed on the string in the ground. During this operation while the drill was being rotated, the handle hit the faceplate."

In analyzing the workload placed on the astronaut by this task, the author notes two major problem areas for performance: "there is considerable manipulation required in just connecting and disconnecting drill strings and casing to the drill power head, and, many operations require grasping and turning objects with the gloved hand; this results in considerable hand fatigue."

From these reviews it should become obvious to the reader that while individual problems exist, they can easily be compounded into even larger problems by other unusual environmental features of the moon. In man's attempt to anticipate such problem areas, he has also created new problem areas. An example of such a problem can be seen in Lehr's (1968) report concerning the deployment of ALSEP, in which he states ... "using the method of the previous design, i.e., carrying with the Experiment Handling Tool (EHT) in the side pocket, it was determined that the tool's handle design did not correctly fit the gloved hand. The obvious cause is that both the EHT and the Apollo Lunar Hand Tools are designed for right-hand carry." If this is the design philosophy, multi-handed use of tools is not readily feasible, even though we recognize the fact that hand fatigue is a problem. Such a design philosophy might necessitate longer and more frequent rest periods, extending the length of lunar tasks.

Effects of Lunar Environment on Drill Operation

1. Size - NONE
2. Atmosphere - NONE
3. Temperature - NONE

4. Topography - The cohesiveness of the surface will affect traction and balance.

5. Lighting - Variable lighting conditions could make drilling operations difficult unless an artificial light source is employed.

6. Radiation - NONE

7. Gravity - The limb and whole body movements required to set up the drill could be difficult to perform in the pressurized suit and 1/6 gravity environment. Reach and balance could be a problem. Reaching the drill handle located 26 inches above the surface could be a problem.

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